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Vacuum Technic: Speed of Pumping and Molecular Flow

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IN THE avid search for new facts and information the technics which we use are often allowed to develop in a hit-or-miss empirical manner. Our attentions are focused on the ends rather than on the means. A pause for reflection on our methods usually stimulates improvements and allows further interpretation of our results.

In all modern physics the most time-consuming experimental technic is probably the one described as "vacuum plumbing." This technic includes many ramifications. In the present article we shall limit discussion to speed of pumping and molecular flow.

High vacuum technic as we know it today began in 1916 with Langmuir's invention of the condensation type of diffusion pump. This pump, in addition to ease of construction and operation, possesses the remarkable characteristics of having ". . . no definite lower limit (other than zero) below which the pressure cannot be reduced"[1] and a speed which some writers have overexuberantly called "theoretically infinite." The invention of this relatively quick and easy way of producing extremely low pressures paved the technical way for a great many investigators to explore the electronic and atomic physics of "empty space." An almost inordinate number of vacuum systems mushroomed into existence. For about fifteen years these systems were similar in two regards: the condensation pumps were fashioned after Langmuir's original designs; and too little heed was given to the laws of molecular flow, especially in the geometry of the connecting tubing. In the last few years important modifications of Langmuir's designs have been made and vacuum systems have been built that more adequately meet the requirements of ever greater speed and ever lower pressure.

The principal requirements of a vacuum system are the production and maintenance of a specified low pressure called a "vacuum," a minimum of involved time, and simplicity and convenience of construction.

In the study of a vacuum system it is of utmost importance to distinguish clearly between minimum pressure, rate of gas removal and speed. Each of these three characteristics is determined not alone by the condensation pump, but by the speed or speeds of all the connecting tubing and by the fore pump as well. The choice of a condensation pump or of any component part of a vacuum system to meet some desired requirement must be based upon a reasonable understanding of the fundamental concepts of molecular flow. In this article we shall survey the essential ideas[2] for such an understanding.

[1] I. Langmuir, Gen. Elec. Rev. **19**, 1060 (1916).

[2] Many of these ideas are briefs, extensions or modernizations of those appearing in articles by M. Knudsen, Ann. d. Physik **28**, 75 (1909) and I. Langmuir, ref. 1; and in summaries by S. Dushman, *High Vacuum* (Gen. Elec. Rev. Press, 1922), pp. 30–42; L. Dunoyer, *Vacuum Practice* (Van Nostrand, 1926), Chap. I; F. H. Newman, *The Production and Measurement of Low Pressures* (Van Nostrand, 1925), pp. 25–31; and J. Strong, *Procedures in Experimental Physics* (Prentice-Hall, 1938), Chap. III.

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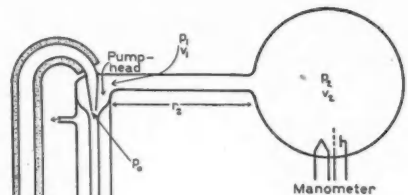

FIG. 1. High vacuum system with simple connecting tube.

DEFINITION OF SPEED OF PUMPING

The term *pumping* refers to the condition in which gas flow is present. The time-rate of gas flow is $d(vp)/dt$, where the *quantity* of gas is the product pv. The rate of gas flow is directly proportional to the pressure difference $p'-p''$ responsible for the flow. Thus, $d(vp)/dt = S(p'-p'')$, where the proportionality factor S is *defined* as the *speed of pumping;* that is,

$$S \equiv \frac{1}{(p'-p'')}\frac{d(pv)}{dt} = \left[\frac{v}{(p'-p'')}\frac{dp}{dt}\right]_{v=\text{const}} = \left[\frac{p}{(p'-p'')}\frac{dv}{dt}\right]_{p=\text{const}}. \quad (1)$$

The dimensions of S are *volume per unit time* and the unit may be *cubic centimeters per second.* One must not be confused by this unit and its dimensions: speed is not defined as a time-rate of *volume* but as a time-rate of *quantity* per unit pressure difference. This quantity, defined as the product pv, may also be thought of as the number of gas molecules, since $pv = nkT$.

No subscripts are placed on p and v in referring to the element of gas $d(vp)$ because, from Boyle's law, it is merely necessary that p and v be measured simultaneously and each at the same place. This place may be in the exhaust chamber, in some intermediate part of the vacuum system, in free atmosphere or elsewhere. We usually think of the element of gas as in a chamber of constant volume, say, v_2, which is being evacuated; with these special conditions the element of gas is $v_2 dp_2$, and speed of pumping is simply the time-rate of decrease of pressure in a chamber of unit volume when unit pressure difference is responsible for the flow. Another special case is the one in which the pressure remains constant and the volume is allowed to decrease; as we shall mention later, this case is illustrated by most mechanical fore pumps and the speed, with certain provisions, is simply the "free volume displacement." To avoid possible confusion because of these various special ways in which speed may be expressed, the reader is advised to think of the gas element in its general form $d(vp)$.

Let us become better acquainted with the general concept of speed by a simple application. Suppose the pressure p_2 in the vessel v_2 of Fig. 1

NOTATION USED IN THIS ARTICLE

S = pumping speed $\equiv \dfrac{d(vp)/dt}{p'-p''} = \dfrac{q}{p'-p''}$;

E = rate of exhaustion $\equiv \dfrac{d(vp)/dt}{p'} = \dfrac{q}{p'}$;

p = pressure; v = volume.

A vacuum system is analyzed conveniently in terms of four separate parts. Subscripts are attached to S, E, v and p to designate the particular part of the system under discussion:

(1) Main chamber and high vacuum connecting tubing,
v_2 = volume of chamber,
p_2 = pressure at chamber,
$p_2 - p_1$ = pressure difference across tubing,
S_2 = speed of tubing,
E_2 = exhaust rate of tubing;

(2) Condensation pump,
v_1 = volume of pump head,
p_1 = pressure at pump head,
$p_1 - p_0$ = pressure difference across pump,
S_1 = speed of pump,
E_1 = exhaust rate of pump;

(3) Fore vacuum connecting tubing,
$p_{f2} - p_{f1}$ = pressure difference across tubing,
S_{f2} = speed of tubing,
E_{f2} = exhaust rate of tubing;

(4) Fore pump,
$p_{f1} - p_{f0}$ = pressure difference across pump,
S_{fp} = speed of pump,
E_{fp} = exhaust rate of pump.

Parts 1 and 2 comprise the high vacuum system of speed S_{eff}, exhaust rate E_{eff} and pressure difference $p_2 - p_0$. The symbols p_{2e}, p_{1e} and p_{0e} are used to refer to the final, equilibrium values of p_2, p_1 and p_0, respectively.

Parts 3 and 4 comprise the fore vacuum system of speed S_f and exhaust rate E_f.

E_e is the actual rate of exhaustion of the entire system as a unit.

is being reduced by gas flow through the tubing r_2. By substituting in Eq. (1), using the subscripts as labeled in the figure, we obtain for the speed S_2 of the tubing r_2 the equation

$$S_2=\left[\frac{v_2}{p_2-p_1}\frac{dp_2}{dt}\right]_{v_2=\text{const}}. \qquad (2)$$

We emphasize that it is meaningless to say that S_2 is the speed *at* the chamber v_2. Speed always refers to a *section* of a vacuum system and *never to a point* in the system; it does not make sense to speak of a pressure difference at a point.

Dynamic method for measuring speed. If p_1, p_2, v_2 and dp_2/dt are measured, the speed S_2 of the tubing may be calculated from Eq. (2). This is called the *dynamic method* for determining speed. The measurement of p_1 is facilitated in practice by inserting between r_2 and the pump a second chamber containing a manometer. The pressure rate dp_2/dt is the slope of the curve p_2 *versus* time.

More precisely speaking, in taking p_2-p_1 as the pressure difference in Eq. (2), we tacitly assume the volume of r_2 to be negligible. If this assumption is not justified, p_1 is not properly assigned. Since the element of gas v_2dp_2 leaving v_2 will be augmented in passing through r_2 (r_2 also being evacuated), the dynamic method is not practical.

Pressures p_2 and p_1 vary with time, as qualitatively indicated in Fig. 2. After some time these pressures reach equilibrium values p_{2e} and p_{1e}, where p_{2e} is larger than p_{1e} if there is a finite gas

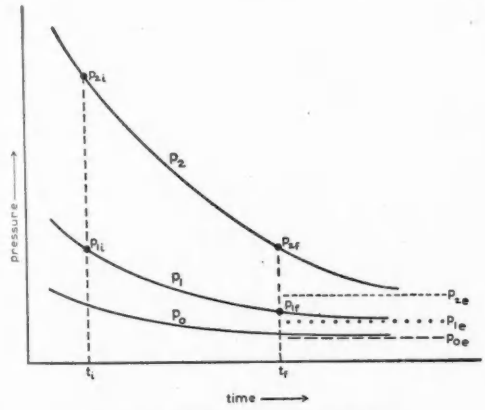

FIG. 2. Pressure as a function of time.

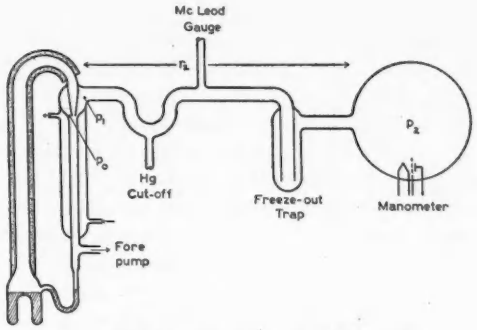

FIG. 3. High vacuum system with complex connecting tubing.

flow. A gas flow will exist in any practical system because of the presence of a leak (deliberate or otherwise), evaporation of condensed vapors, outgassing of the glass, wax, stopcock grease, or any metal in the vacuum system. In an ideally tight and outgassed system, no gas flow exists at equilibrium and $p_{2e}=p_{1e}=p_{0e}$, where p_{0e} is the limiting pressure of the pump. In the event of equilibrium, with zero or with finite gas flow, we have static, rather than dynamic, conditions.

Static method for measuring speed. We may have a calibrated leak in the system by which a known quantity of gas per unit time is introduced to the chamber v_2; the pressures p_1 and p_2 eventually reach equilibrium values as indicated in Fig. 2. These equilibrium values may be measured and, with the known quantity $d(vp)/dt$, the speed S_2 may be calculated from Eq. (1) or (2). This *static method* of measuring the speed obviates the difficulties attending the proper assignment of p_1 since the tubing is not being evacuated.

Complex connecting tubing. The difficulties attending the measurement of speed by the dynamic method are greatly enhanced if the simple tubing r_2 of Fig. 1 is replaced by a complex connecting system such as the one illustrated in Fig. 3. This latter system, which includes the type of gadgets[3] usually found in

[3] In particular, a freeze-out trap cannot be dispensed with if the pressures desired are lower than the vapor pressure at room temperature of the fluid used in the pump. At room temperature the vapor pressure of mercury is about 5×10^{-3}; of butylphthalate, about 1.5×10^{-4}; of Apiezon *A* oil, about 2×10^{-5}; and of special "Octoil," about 10^{-7} mm-of-mercury. Oils—"Octoil" to a lesser degree—decompose with use, especially if exposed to air while hot, and yield decomposition products of much

practice between the pump and the exhaust chamber, contains several distributed volumes that are being evacuated and the simple dynamic method for S_2 is not practical. The static method, however, may be used without difficulty.

Obviously, in the production and maintenance of a vacuum the dynamic and static conditions are successively involved and we must keep in mind their essential difference when making practical application of the speed.

A frequently convenient expression is obtained by integrating Eq. (2) for the case where the variation in p_1 is negligible; thus,

$$S_2=\left[\frac{v_2}{t}\log_e\frac{p_{2i}-p_1}{p_{2f}-p_1}\right]_{\substack{v_2=\text{const.}\\ p_2=\text{const.}\\ S_2=\text{const.}}} \tag{3}$$

where t is the time required to reduce the pressure p_2 from p_{2i} to p_{2f}. For some pressure ranges S_2 is not constant and the value of S_2 in Eq. (3) must be considered as some average value. Also, if the variation in p_1 is not negligible or if some average value of p_1 will not suffice, it is necessary to evaluate p_1 in terms of p_2 in order to perform the integration; in this event the simplicity of the integration is lost.

A Pump

Let us now turn our attention to the pump. First we shall speak specifically about a diffusion pump or, more precisely, a condensation type of high vacuum diffusion pump, and second, about a rotary fore pump. Our general statements apply, however, to any type of pump.

A pump has two principal parts: the part through which the gas flows due to a pressure difference p_1-p_0 (see Figs. 1 and 3); and the part in which the action takes place that keeps $p_0<p_1$. The former part determines only the speed of the pump; the latter part determines the minimum pressure (for zero gas flow) which the pump will produce. Before discussing briefly the action of the pump, we note that the section of the pump which determines the speed is made up of two parts: (1) the nozzle or orifice, which, in a condensation pump, is usually in the form of an annulus; (2) the region connecting this orifice with the high vacuum lead. We shall refer to this second region as the *pump-head*.

Condensation pump. It is well known that the speed of a condensation pump is "very great" and that its limiting pressure is "almost zero." Let us examine these phrases. With an operating pump, we have mentioned p_0 as the pressure at, or just below, the nozzle where the gas molecules are struck by the fast-shooting vapor molecules. A limiting pressure of $p_0=0$ cannot be realized for two reasons: (1) the vapor molecules emerging from the nozzle and traveling to the condensing wall are not all unidirectional in velocity; (2) some of the bombarded gas molecules will rebound or back-scatter from the vapor molecules and from the condensing wall.[4] The conditions yielding the minimum nozzle pressure $p_0=p_{0e}$ are ideal but, with special care, can be approximated in practice. These conditions are that the fluid boil at the optimum rate, that the fore-vacuum conditions be "adequate" (discussed later), and that there be zero gas flow.

Strictly speaking, the "pressure" p_0 is a "unidirectional pressure"—the *backward* component rather than the *forward* component of the actual pressure, where the sense is determined as away from the pump-head. Also, strictly speaking, p_1 and p_2, are really measured under conditions of resultant mass-motion of the gas; and similar qualifying statements about "direction of pressure" are appropriate.

Speed of a condensation pump, S_1. The speed of the condensation pump we may call S_1, obtained by applying Eq. (1) to the orifice and pump-head of the pump where the pressure difference responsible for the gas flow is p_1-p_0. To measure S_1 dynamically we might seal-off the pump at the pump-head and, were it practical, determine p_0, p_1, v_1 and the time-rate of decrease of p_1. Actually, dp_1/dt is too large to be measurable. But if r_2 (Fig. 1) is short in length and large in diameter, p_1 and p_2 will be approxi-

higher vapor pressure. A fractional distillation or self-purifying pump of several stages greatly helps in preventing these volatile products from reaching the high vacuum part of the system. Even so, a cold baffle, if not a freeze-out trap, must be used to prevent the deposition of oil vapor and seemingly inevitable, soft, gummy "gunk" on the nicest parts of the vacuum system. One would like to dispense with the freeze-out trap for two reasons: to avoid the nuisance and expense of the refrigerant (e.g., liquid air), and to increase the pumping speed.

[4] Back-scattering of vapor and gas molecules is reduced by careful design of the pump. Some of the features of design are discussed in the last section.

mately equal and we shall have effectively increased v_1 to v_1+v_2. In this way, dp_1/dt (or its equivalent, dp_2/dt) may be reduced to a measurable value, and, if v_1+v_2, p_1 and p_0 all were known, S_1 could be evaluated. But this requires a measurement of p_0.

Unfortunately, we cannot measure p_0, so *we cannot measure the speed of an operating pump.* By attaching the pump to a small, tight, well outgassed system in which p_{2e} is measured, and assuming that p_0 equals p_{2e}, we may approximate a measurement of p_0 by a static method. Actually, however, p_0 is always less than p_{2e} and, for some pumps and systems, is very much less because of the presence of rather large gas flow. Much of the present article is concerned with the dilemma of wanting to know p_0 and of not knowing how to measure it.

Incidentally, either the dynamic or the static method of measuring speed may be applied to a pump that is not pumping, that is, to a pump connected in the vacuum system simply as a section of tubing; for example, connected in place of r_2 in Fig. 1. In this case a special manometer must be inserted just below the nozzle to allow the measurement of the proper p_0. Such a method would give the true speed S_1 but, not being very convenient, has not been used.

Rate of exhaustion of a pump, E_1. Since we are unable to measure p_0 conveniently, we define and measure a quantity E that does not involve p_0. This quantity E, called the *rate of exhaustion*,[5] is defined for a pump, using the notation of Figs. 1 and 3, as

$$E_1 \equiv \left[\frac{v_1}{p_1}\frac{dp_1}{dt}\right]_{v_1=\text{const}} = \left[\frac{v_1}{t}\log_e\frac{p_{1i}}{p_{1f}}\right]_{\substack{E_1=\text{const.}\\ v_1=\text{const.}}} \tag{4}$$

In case E_1 is dependent on pressure in the range of integration p_{1i} to p_{1f}, either the integration of Eq. (4) cannot be made or the value of E_1 so obtained must be considered as an average value for the pressures involved. The quantity E_1 is measured by the dynamic method (by attaching a large chamber v_2 to v_1 so that $p_1=p_2$) or by the static method (by measuring p_{1e} with a known rate of gas flow $d(vp)/dt$). The static method is more often used.

While S_1 is independent of pressure (only for low pressures, as we shall see presently), E_1 is a function of pressure, being equal in magnitude to S_1 when $p_1 \gg p_0$ and decreasing to zero when $p_1=p_0$. This is seen in Eq. (5), obtained by combining Eqs. (1) and (4):

$$E_1 = S_1(1-p_0/p_1). \tag{5}$$

Consequently, one must specify the pressure p_1 under which E_1 is measured; too often this specification is neglected. Insensitivity of E_1 to pressure indicates that p_0 is much smaller than p_1, a desirable pump characteristic. Actually, many pumps do exhibit a relatively constant exhaust rate in the ordinary pressure range of 10^{-3} to 10^{-6} mm-of-mercury. For pressures less than 10^{-6}, however, E_1 is usually considerably less than S_1.

Although the quantity E is introduced specifically for a condensation pump, we shall find the rate of exhaustion a convenient characteristic of a fore pump and, indeed, of any section of the vacuum system having a pump at the low pressure side.

Speed of a fore pump. The *free volume displacement* $\Delta v/\Delta t$ of an oil-sealed rotary fore pump is the time-rate at which volume is swept out by the rotating member of the pump. This displacement is calculated directly from the geometry and the number of pump rotations per second. The term *free* means that p_{f0} is very much smaller than p_{f1}, so that in each rotation of the pump the *entire* volume swept out shall be filled (at pressure p_{f1}) with new gas from the system. Eq. (1), rewritten for the fore pump, is

$$S_{fp} = \left[\frac{p_{f1}}{p_{f1}-p_{f0}}\frac{dv_1}{dt}\right]_{p_{f1}=\text{const.}}$$

where S_{fp} is the pumping speed of the fore pump, p_{f1} is the pressure at the top of the pump-head[6]

[5] Although E has the dimensions and units of speed, it is not really a speed. Langmuir (ref. 1) introduced E as the "speed of exhaustion" and many writers have deleted the phrase "of exhaustion" with a great deal of consequent confusion of E with S. The use of the phrase "rate of exhaustion" or "exhaust rate" avoids the double meaning of the term speed and, it is hoped, minimizes the confusion arising from the equivalent units. There is in current practice a rather vigorous trend to call E_1 the speed of the pump. If this trend persists we may be obliged in the future to redefine speed accordingly and to call S the conductance, a term that is introduced in the next section as a geometrical characteristic of a pump or of a section of tubing.

[6] By "pump-head of a fore pump" is meant the section of the vacuum system between the oil-sealed chamber containing the rotating member and the neck to which rubber tubing is usually fastened. As with the condensation pump, the pump-head is an integral part of the pump.

and p_{f0} is the minimum or residual pressure in the pump chamber during a complete turn of the pump. Because of the residual pressure p_{f0}, the effective pumping volume per rotation is less than the geometrical volume Δv and is approximately equal to $(p_{f1}-p_{f0})\Delta v/p_{f1}$. Then, for relatively high pressures,

$$S_{fp} \doteq \frac{p_{f1}}{p_{f1}-p_{f0}} \frac{p_{f1}-p_{f0}}{p_{f1}} \frac{\Delta v}{\Delta t} = \frac{\Delta v}{\Delta t}$$

and, except for the effect of the resistance of the pump-head, the speed of the fore pump is simply the free volume displacement. As discussed in the next section, for large values of p_{f1} the pump-head resistance is negligibly small; for lower pressures (p_{f1} less than 10^{-1} or 10^{-2} mm-of-mercury) the pump-head resistance may be large and S_{fp} much less than the free volume displacement.

The rate of exhaustion of a fore pump,

$$E_{fp} \equiv \frac{dv_1}{dt} = \frac{p_{f1}-p_{f0}}{p_{f1}} \frac{\Delta v}{\Delta t} = S_{fp}\left(1-\frac{p_{f0}}{p_{f1}}\right),$$

is a function of pressure, being equal to S_{fp} at high pressures, decreasing rapidly at lower pressures, and approaching zero as p_{f1} approaches p_{f0}. As actually measured, E_{fp} includes, of course, the pump-head resistance.

Resistance to Molecular Flow

We have defined speed and discussed several practical applications of the definition. Our concept of speed can be enriched and extended to the entire vacuum system as a unit by a brief survey of certain laws of molecular flow.

The difference between the speed of the condensation pump and the speed of the high vacuum system (or, between the speed of the fore pump and the speed of the fore system) is due to the impedance of the connecting tubing. The term *impedance* refers to the combined effects of distributed volume and resistance of the tubing. Under dynamic conditions, as previously discussed, it is not possible to distinguish clearly between volume and resistance, because any finite section of a system contains both. Under static conditions, however, only the resistance is significant.

On the basis of kinetic theory (and some empiricism) Knudsen[2] derived, and experimentally checked, the following equation for q, the quantity of gas flowing *steadily* (static conditions) per second through a straight cylindrical tube of diameter D and length L:

$$q = \frac{d(pv)}{dt} = c_1 p(p_2-p_1) + c_2 \frac{(1+c_3 p)}{(1+c_4 p)}(p_2-p_1), \quad (6)$$

where p_2-p_1 is the pressure difference in dynes per square centimeter across the tube; p is the mean pressure, defined as $(p_1v_1+p_2v_2)/(v_1+v_2)$; c_1 is $\pi D^4/128\eta L$; c_2 is

$$1\Big/\left(\frac{8}{(2\pi)^{\frac{1}{2}}}\frac{1}{D^2}+\frac{6}{(2\pi)^{\frac{1}{2}}}\frac{L}{D^3}\right)\sqrt{\rho},$$

the coefficient of molecular flow at low pressures through an orifice[7] and a tube; c_3 is $(\sqrt{\rho}/\eta)D$; and c_4 is $1.24(\sqrt{\rho}/\eta)D$, where η is the coefficient of viscosity and ρ is the density measured at a pressure of 1 dyne cm^{-2}. For air at 20°C, η is 181×10^{-6} cgs units.

The term $c_1p(p_2-p_1)$ in Eq. (6) dominates at high pressures and, when equated to q, is known as Poiseuille's law. At lower pressures—pressures for which the mean or average free path λ is of the order of magnitude of D—the viscosity loses its meaning and Eq. (6) is dominated by the second term. Also, as the pressure is decreased, the ratio $(1+c_3p)/(1+c_4p)$ approaches unity. Thus, Eq. (6) becomes

$$q = \left[\frac{(p_2-p_1)}{\left(\frac{3.184}{D^2}+2.394\frac{L}{D^3}\right)\sqrt{\rho}}\right]_{\text{low press.}} \quad (7)$$

Although q is a function of pressure difference, it is independent of pressure for sufficiently low pressures.

The density of the gas is given by the gas law $\rho=pM/RT$, where M is the molecular weight (28.8 for air) and R is 8.315×10^7 erg deg.$^{-1}$. In Eqs. (6) and (7) ρ is to be measured at $p=1$ dyne cm^{-2}; so, by substitution, $\rho=11.8\times10^{-10}$ gm cm^{-3} for air at a pressure of 1 dyne cm^{-2}.

[7] The coefficient for the orifice is included in c_2 on the assumption that the pressure p_2 is measured in a large chamber to which is attached the tube in question. The orifice is simply the entrance to the tube.

Equation (6) or (7) bears a close analogy with Ohm's law for electric circuits: q, the quantity of gas moving per second, corresponds to current; the pressure difference p_2-p_1, to potential difference; and the reciprocal of the coefficient of p_2-p_1, to resistance. In fact, we define resistance[8] to molecular flow as

$$r\equiv\frac{(p_2-p_1)}{q}=\left[\left(\frac{3.184}{D^2}+2.394\frac{L}{D^3}\right)\sqrt{\rho}\right]_{\text{low press.}} \quad (8)$$

Two resistive factors are involved in the right-hand member of Eq. (8): the resistance of the entrance of the tube, given by the area factor[7] $1/D^2$; and the resistance of the tube due to its length, given by the factor L/D^3. Obviously, one may not neglect the resistance of the orifice of a section of tubing unless the length of the section is large compared with its diameter.

Strictly speaking, Eq. (6) simplifies to Eq. (7) only when $\lambda\gg D$. Actually, for $\lambda>0.4D$, Eqs. (6) and (7) differ by less than 5 percent as shown by Knudsen's data.[2] For air at room temperature and at a pressure of p bars, $\lambda\doteq 9/p$ cm (1 bar is 0.75×10^{-3} mm-of-mercury). Thus, for Eq. (7) or (8) to hold within 5 percent at a pressure of 10^{-2} mm-of-mercury, the tube diameter must be less than 3 mm, or at a pressure of 10^{-3} mm-of-mercury, less than 3 cm.

Relation of resistance, r, to speed, S. The dimensions of r are $[TL^{-3}]$ and the unit is *second per cubic centimeter*. This unit is the reciprocal of the unit of speed and, following from the definitions, there exists a simple reciprocal relation between resistance and speed. Consequently, Eq. (8) provides a very convenient way to determine the pumping speed of a geometrically simple section of a vacuum system.

Pumping speed, now seen to be a characteristic of the geometry (for a given gas), is analogous to the electric conductance (reciprocal resistance) of a wire, or series of wires, which may be used to discharge a condenser. Conductance, while not a function of the potential difference across the condenser nor of its capacitance, is, nevertheless, a measure of the rate at which the condenser will discharge. Indeed, the rate of discharge of a condenser is a standard dynamic method of measuring the "speed" or conductance of a (high resistance) wire. The static method of measuring the speed of pumping is actually the "Ohm's law" method with a "voltmeter" and an "ammeter" in which the "meters" are comparatively awkward and as such may escape recognition.

Under dynamic conditions the impedance rather than resistance controls the gas flow. An alternative analysis, more general but also more complex than the discussion in the present article, would treat the impedance, which includes the volume "reactance." Such an analysis would use the analog of Kirchhoff's laws for varying direct current in electric circuits and would evaluate either the gas flow or the pressure at any given time in any part of the vacuum circuit.

Just as in the case of an electric circuit, the effective or combined resistance of several series-sections of a vacuum circuit is the sum of the component resistances,

$$r_{\text{eff}}=r_1+r_2+r_3+\cdots,$$

and, therefore,

$$1/S_{\text{eff}}=(1/S_1)+(1/S_2)+\cdots. \quad (9)$$

Similarly, the effective speed of a combination of parallel branches of a vacuum circuit is the sum of the individual speeds.

Rate of gas flow, q. Fundamentally more important than the speed of a pump is the rate at which the pump will remove gas. How may we determine q for any time or for any pressure?

The speed of a condensation pump,

$$S_1=q/(p_1-p_0),$$

although not measurable, has the desirable characteristic of being independent of pressure for the low pressures in which we are interested. The limiting pressure p_0 also is practically independent of pressure p_1. Then, if we somehow knew S_1 and p_0, we could readily determine q for any pressure p_1.

From the exhaust rate $E_1=q/p_1$ we may evaluate q directly for the corresponding pressure p_1;

[8] If we extract the ρ- and η-terms in Eqs. (6) and (7), the resistance is a characteristic of the geometry of the tube; if we leave in these terms, the resistance or impedance is also a function of the temperature and nature of the gas. Langmuir has suggested that, including ρ and η, we may speak of the nature of the gas as something akin to frequency or inductance in the electrical case. We have used the term *impedance* to include the distributed volumes which, in the analogy, correspond to distributed capacities. With Langmuir's suggestion, the term impedance may include analogs of both types of electric reactance.

and for any p_1 the rate q is the slope of the curve E_1 *versus* $1/p_1$. Although a knowledge of E_1 for all pressures suffices for determining q, a knowledge of S_1 and p_0 is to be preferred in practice for two reasons: two numbers are more convenient than a curve; and S_1 rather than E_1 must be used in calculating the speed of a series circuit [Eq. (9)] which includes the pump.

Measurement of E_1 for each of two pressures p_1 and p_1' allows an approximate determination of p_0 from a solution of the two simultaneous equations of the form of Eq. (5). This solution for p_0 is

$$p_0=[p_1p_1'(E_1'-E_1)/(p_1'E_1'-p_1E_1)]_{p_0=\text{const.}} \quad (10)$$

In case p_0 is not constant in the pressure range p_1 to p_1', a mean value of p_0 is obtained from Eq. (10). Once p_0 is known, S_1 may be calculated from a single value of E_1 and q determined for any pressure.

The limiting pressure p_0 is a characteristic of the pump. For a pump that is operated with an adequate fore system, a pump specification of p_0 for, say, $p_1=10^{-6}$ mm-of-mercury or for $q=0$, would aid greatly in the practical description and use of the pump. For an extremely fast pump, the variation in p_0 with p_1 or with q may not be negligible and measurements of E_1 at more than two pressures may be necessary to give the desired information; namely, a value of p_0 for each of several values of p_1. Very few pumps, if any, have been constructed as yet for which a specification of p_0 for a single value of p_1 is not sufficient.

Speed factor of a pump. Recognizing the need for a pump specification in addition to the measured speed, several investigators have used the so-called *speed factor*. This factor, proposed as a semi-empirical pump characteristic, can be measured unambiguously for both condensation and fore pumps; but its quantitative physical significance is rather involved. At best the speed factor is a qualitative index to the order of magnitude of p_0.

The *speed factor of a condensation pump* is defined as the ratio of the rate of exhaustion E_1 to the speed of the annular orifice at the lower boundary of the pump-head. The speed of this orifice for low pressures is assumed to be

$$S_{\text{orifice}}=A/(2\pi\rho)^{\frac{1}{2}}=11{,}600A \text{ cm}^3 \text{ sec}^{-1}, \quad (11)$$

where A is the area of the orifice in square centimeters. This is the orifice term from Eq. (6) or Eq. (7) and may be evaluated from the geometry of the pump. Then, if E_1 is known, the speed factor is readily determined. This factor, being proportional to E_1, must be referred to the pressure for which it is measured.

Equation (11) does not give the true speed of the pump, principally because of the deterring effect of the pump-head resistance. Furthermore, Eq. (11) does not give the correct speed of the orifice, because in a pump one does not find the boundary conditions assumed in the derivation, namely, a hole in an infinitesimally thin sheet. If we could evaluate easily and correctly the geometrical speed of the pump-head, as well as of the orifice, using Eq. (8), we would have directly the true speed S_1 of the pump. Knowing S_1 and the exhaust rate E_1, we could determine p_0 from Eq. (5). The correct evaluation of the pump speed from the geometry might be made if the pump were designed with this task in mind, but this is not general practice. Confronted with the difficulties of this evaluation, we use the idealized part of the orifice term in the definition of the speed factor and make use of this factor as a qualitative index to the value of p_0. The speed factor is always less than unity since $S_{\text{orifice}}>S_1>E_1$; but, in general, the larger the speed factor, the lower is p_0 and, hence, for a given pressure p_1, the larger is the quantity of gas being removed per unit time and the lower is the minimum pressure that the pump will produce.

It may be seen that the two virtues of a condensation pump, a high speed and a low value of p_0, are not compatible; high speed is a property of a wide annular orifice, and a low value of p_0 is obtained with a narrow orifice. The tendency in pump design is toward higher speeds or wider orifices, but the value of p_0 is still so low that the sacrifice has not been serious; indeed, it is not certain that the increase in p_0 in studies of speed factor with various annular orifice widths has been detected.

The *speed factor of a fore pump* (or the "merit factor," specified for Cenco pumps) is the ratio of the exhaust rate E_{fp} measured at a pressure p_{f1} of 10^{-3} mm-of-mercury to the free volume displacement. This specification of p_{f1} as 10^{-3}

mm-of-mercury may seem rather stringent since the minimum equilibrium value of p_{f0} of many used fore pumps is greater than 1 micron and, hence, such a low value of p_{f1} is never reached; but a fore pump in such poor condition will not serve satisfactorily in series with a fast condensation pump. A new Hyvac pump has a rated merit factor of 0.46; a new Megavac pump, 0.40.

Features of the Entire Vacuum System

We have discussed the essential ideas involved in the speed of each of the four component parts of a vacuum system: the chamber and connecting tubing of the high vacuum system, the condensation pump, the fore system connecting tubing and the fore pump. Now we shall combine these ideas and investigate some of the characteristics of the entire vacuum system as a unit.

Equilibrium pressure p_{2e}. In any practical system, the final equilibrium pressure p_{2e} in the main chamber is determined by the balance of the rate at which gas is supplied by the system (leaks, vapors, outgassing, etc.) with the rate q at which gas is removed from the system. Only in the ideal case of zero flow is the final pressure equal to p_{0e}°. In a given system having adequate fore speed the rate of gas removal is given by the relation

$$q = d(vp)/dt = S_{\text{eff}}(p_2 - p_0) = E_{\text{eff}} p_2, \qquad (12)$$

where S_{eff} is the speed of the series combination [Eq. (9)] of the condensation pump and the connecting tubing of the high vacuum system, and E_{eff} is the corresponding rate of exhaustion defined by this relation. In a given system with pressure p_2, q and p_{2e} are limited by p_0, measurement of which was discussed in the preceding section.

Speed of the high vacuum system. The effective speed of the high vacuum system, defined by Eq. (9) or (12), is usually very much less than the pump speed because of the hindrance of the connecting tubing. The first rule in choosing tubing for a fast system is to have it large and short. The importance of this geometry is not generally appreciated. In the following illustrative calculations the speeds of connecting tubes are determined from Eq. (8), which is valid only for static conditions and for pressures less than 10^{-2} mm-of-mercury.

If the pump in Fig. 1 has a speed S_1 of 1070 $\text{cm}^3\ \text{sec}^{-1}$ (a pump of relatively low speed, having an annular area of about 10 mm^2), a straight connecting tube r_2 (Fig. 1) of 1 cm diameter and 10 cm length will result in an effective speed of 535 $\text{cm}^3\ \text{sec}^{-1}$, one-half the speed of the pump.

A moderately fast pump may have a speed of 10,000 $\text{cm}^3\ \text{sec}^{-1}$, a pump with an annular area of about 1 cm^2. The connecting tubing r_2 between this pump and v_2 (Fig. 1) must have a conductance greater than 100,000 $\text{cm}^3\ \text{sec}^{-1}$ in order that the effective speed may be 9000 $\text{cm}^3\ \text{sec}^{-1}$, 90 percent of the speed of the pump. For this effective speed, the tubing r_2, if it is 10 cm in length, must have a diameter of 5.2 cm. A tube of these dimensions may seem "resistanceless" but, nevertheless, will reduce the pumping speed by 10 percent.

If the pump of speed 10,000 $\text{cm}^3\ \text{sec}^{-1}$ be connected with a tube 3 cm in diameter and 50 cm long and having no bends in it, the effective pumping speed is reduced to 3800 $\text{cm}^3\ \text{sec}^{-1}$. A single 90° bend in the tubing is equivalent to perhaps an additional 50 cm of tubing (perhaps 100 cm; apparently the exact equivalent length of a bend is not known), reducing the effective speed to about 2400 $\text{cm}^3\ \text{sec}^{-1}$. A conventional freeze-out trap in the connecting tube may further reduce the speed to 1200 $\text{cm}^3\ \text{sec}^{-1}$. Such a system is typical of average *well-designed* setups. Increasing the speed of the pump from 10,000 to 50,000 $\text{cm}^3\ \text{sec}^{-1}$ (an unusually fast pump) results in only a very slight increase in the effective pumping speed, namely, from 1200 to about 1400 cm sec^{-1}. Only after the speed of the connecting tubing has been increased may one speed up his pump to advantage.

Obviously, for fast systems, our remarks about the geometry of the tubing apply as well to the design of the pump-head. In extremely fast, specially designed systems, the pump-head cannot be distinguished from the connecting tubing.

Speed of the fore system. Eq. (9) may be written for the fore system as

$$1/S_f = (1/S_{fp}) + (1/S_{f2}). \qquad (13)$$

In evaluating the tubing speed S_{f2} for use in Eq. (13) we use Eq. (6) for pressures higher than 10^{-2} mm-of-mercury; for lower pressures Eq. (8) may be used. Remember that, for pressures

higher than about 10^{-1}, S_{f2} is linear with pressure but that S_{fp} is constant for an oil-sealed rotary fore pump.

Sample calculations to illustrate the importance of using fast connecting tubing with fast fore pumps follow: A new Cenco Hyvac fore pump has a rated speed S_{fp} of about 170 cm^3 sec^{-1} (an exhaust rate of about 80 cm^3 sec^{-1} at low pressures). A section of 5-mm tubing 100 cm long has a speed of 15 cm^3 sec^{-1}. A fore vacuum system containing a new Hyvac and this connecting tubing has a speed S_f of only 13.9 cm^3 sec^{-1}. If the length of the 5-mm tubing were reduced to 25 cm, the fore speed would be 44 cm^3 sec^{-1}, one-fourth the speed of the pump. In many actual systems in which a Megavac pump is used (a Megavac pump has a rated speed about 2.6 to 5 times faster, depending on speed of rotation, than a Hyvac) and whose connecting tubing is unalterably slow, a Hyvac would serve just about as well at low pressures. At pressures above about 10^{-1} mm-of-mercury the speed of the Megavac is used to advantage even with slow connecting tubing.

Rate of exhaustion of entire system. The quantity of gas q being removed per unit time from the main exhaust chamber must travel through the entire system, including the fore pump. This quantity is given by

$$q = E_f p_{f2} = E_a p_2, \tag{14}$$

where p_2 is the pressure in the main chamber, p_{f2} is the fore pressure and E_a, defined in this relation, is called the *actual rate of exhaustion*. Were the fore system adequate, we would write E_{eff} in place of E_a; but, if the fore system is not able to handle as large a quantity q as the high vacuum system is capable of delivering, E_a will be less than E_{eff}. An adequate fore system is, therefore, one that allows E_a to be a maximum, that is, to be equal to E_{eff}.

This criterion for adequacy applies strictly only for a static condition in which all the gas passing through the fore pump comes from the main chamber. In the case of a dynamic condition (tubing being evacuated or gas being introduced by leakage, outgassing, etc., between the main chamber and the fore pump) the rate at which gas is entering the fore pump is higher than the rate at which gas is removed from the main chamber; and the exhaust rate of the fore system, to be adequate for a dynamic condition, must be increased proportionately.

As the pressure p_2 decreases, a fore system that is not adequate at one pressure may become adequate at some lower pressure. For example, with E_{eff} equal to 40,000 cm^3 sec^{-1}, a fore system of exhaust rate $E_f = 44$ cm^3 sec^{-1} with $p_{f2} = 10^{-2}$ mm-of-mercury will keep E_a less than E_{eff} until p_2 is reduced to less than 4×10^{-5} mm-of-mercury. At the "taking hold" pressure, E_a is 44 cm^3 sec^{-1} and increases to the value E_{eff} as p_2 decreases. It is evident that the condensation pump or the high vacuum system does not pump at the maximum rate upon "taking hold," or even soon after "taking hold," unless the fore system is exceedingly fast.

The actual speed of the entire system, determined by the geometry, is independent of operating conditions. With an inadequate fore system, therefore, an excessively high operating value of p_0 for the condensation pump is responsible for the reduction in q.

Time required to produce a "vacuum." The time required for a fore pump to reduce the pressure p_2 or p_{f2} from, say, atmospheric to 10^{-3} mm-of-mercury is, from Eqs. (3) and (4),

$$t_1 = (v_2/\bar{S}_f)\log_e (1.01\times10^6 - \bar{p}_{f0})/(1.33 - \bar{p}_{f0})$$
$$= (v_2/\bar{E}_f)\log_e 1.01\times10^6/1.33 = 13.5 v_2/\bar{E}_f, \tag{15}$$

where an "average" value of p_{f0} is assumed to suffice, and where $\bar{S}_f$ and $\bar{E}_f$, respectively, are properly chosen mean values of S_f and

$$E_f[\equiv S_f(1 - p_{f0}/p_{f2})].$$

Of course, values of p_{2i} and of p_{2f} other than those chosen may be substituted in Eq. (15) to obtain the desired corresponding time t.

The exhaust rate E_f rather than E_{fp} is used in calculating time t; consequently, at low pressures, poorly chosen connecting tubing may defeat the advantage of the faster fore pump; at higher pressures ($>10^{-1}$ mm-of-mercury) the speed of the tubing may be relatively very large, being proportional to the pressure, and E_f approaches E_{fp} in value. For this reason, the time required to reduce the pressure from atmospheric to about 1 mm-of-mercury is almost independent of the choice of tubing.

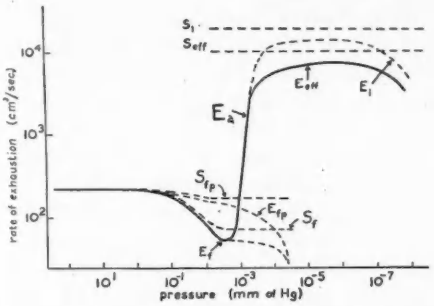

FIG. 4. Rate of exhaustion and pumping speeds as functions of pressure for a vacuum system containing a fore pump and a condensation pump.

Equation (15) applies to the high vacuum part of the system if $\bar{S}_a$, $\bar{E}_a$ and p_0 replace $\bar{S}_f$, $\bar{E}_f$ and $\bar{p}_{f0}$. The proper mean value $\bar{E}_a$ through the pressure range from atmospheric to p_{2f} or p_{2c} may be somewhat difficult to determine. The actual rate of exhaustion E_a varies with pressure as indicated by the solid line in Fig. 4. For comparative study, the speeds are also included in this figure.

It is apparent from Fig. 4 that, in producing a relatively low pressure, say 10^{-5} mm-of-mercury, a very considerable amount of time is spent in the pressure range 10^{-1} to 10^{-3} mm-of-mercury. To reduce this time, either a much faster fore system should be used or else there should be inserted between the high speed pump and the fore pump a smaller (slower) condensation pump which has thereby a much higher "taking hold" pressure. With the present tendency to have larger and faster condensation pumps—some of them "take hold" at 10^{-4} mm-of-mercury or lower pressures—this intermediate pressure range is of increasing concern. Fig. 5 shows the actual rate of exhaustion as a function of pressure for a system containing a second or intermediate condensation pump. In addition to easing the fore pressure requirements, the slower condensation pump continues to pump at very low pressures after the faster pump has practically stopped.

Leaks. The resistance to molecular flow at low pressures (low mean pressures) is enormous; but at higher pressures, those higher than, say, 0.1 mm-of-mercury, the resistance is very much less and is determined by the Poisseuille term in Eq. (6). In this term the resistance is inversely proportional to the mean pressure. At atmospheric pressure the admittance of an orifice or tube is about 10^5 times larger than at low pressures. For this reason a very small hole or crack in the vacuum system between the low pressure and atmospheric pressure is serious.

The calibration of a leak, such as may be used in a static measurement of a speed, may be made by an application of Eq. (6). Or the calibration may be effected experimentally by measuring the volume described in a known time by a pellet of mercury or oil of low vapor pressure moving in a capillary tube with a known pressure difference, one side of the tube being open to the leak which is to be calibrated. For the calibration to have meaning, the mean pressure under which $d(vp)/dt$ is measured must be specified.

FACTORS IN DESIGN OF FAST CONDENSATION PUMPS

Hickman and Sanford[9] have given a rather complete summary of types of condensation pumps. Since 1930, many designs and studies of fast pumps, especially of oil pumps, have been described. We have already mentioned self-purifying oil pumps using several successive stages.[10] We shall describe briefly a few other significant factors in modern pump design.

In the Langmuir type of mercury pump (Fig. 1) the vapor chimney passes through the pump-head, thereby reducing the available space for gas flow. In a fast pump, one having a large nozzle, this chimney is large, with a correspondingly large pump-head resistance and reduced speed. The umbrella type of nozzle introduces the mercury vapor from below, from a central chimney that ends abruptly at the lower boundary of the pump-head. This arrangement allows a faster pump-head and eliminates the usual 90° bend.

Difficulties in the glass blowing of the large glass umbrella nozzle and of the large glass tubing necessary in a fast pump were obviated first by the use of a metal umbrella[11] in a glass

[9] Hickman and Sanford, Rev. Sci. Inst. **1**, 140 (1930). For a summary of other types of pumps see F. H. Newman, ref. 1, Chaps. II and III; S. Dushman, ref. 1, Chap. II; or J. Strong, ref. 1, Chap. III.

[10] K. C. D. Hickman, J. Frank. Inst. **221**, 215, 383 (1935); A. E. Lockenvitz, Rev. Sci. Inst. **8**, 322 (1937); Malter and Marcuvitz, Rev. Sci. Inst. **9**, 92 (1938); etc.

[11] Estermann and Byck, Rev. Sci. Inst. **3**, 482 (1932).

FIG. 5. Rate of exhaustion as a function of pressure for a vacuum system containing a fore pump and two condensation pumps of different speeds in series.

pump and then by the fabrication of an all-metal pump.

With pumps fashioned entirely from metal, nozzle sizes (areas of the annular opening) can be increased with no technical difficulties. One may increase the annular area by increasing either the diameter of the nozzle or the width of the annular opening. As the annular width is increased, so also is the probability that a gas molecule will diffuse back through the vapor stream, resulting in a higher value of p_0 and a lower value of the "taking hold" pressure. This tendency may be partially offset by a more energetic vapor stream or, better, by improved geometry to increase the degree of collimation of the shooting vapor molecules.

The pump will "take hold" when the vapor molecules emerge from the jet with sufficient velocity that, in spite of the bombardments with gas molecules, they are able to maintain an average direction away from the pump-head. Three conditions are involved: the design of the pump, the vapor pressure inside the jet, and the fore pressure. The jet vapor pressure and the fore pressure determine the mean free path of the vapor molecules. The design of the pump refers primarily to the width of the annular orifice and to the geometry of the jet opening. The jet geometry is a factor in the direction of emergence of the vapor stream with respect to the axis of the pump and also in the degree of collimation of the stream.

Higher jet pressures which may increase the "taking hold" pressure, are obtained (1) by thermally insulating, or better, by auxiliary heating of the vapor chimney from the boiler to the jet, and (2) by increasing the heat input to the boiler. However, with increased heater powers the mercury "bumps" badly, with lack of smoothness in pumping rate and with danger of glass breakage. In the case of an oil pump, the higher heater powers seriously damage the oil by decomposition. Moreover, it is possible to overdo the power increase and actually to reduce the "taking hold" pressure and to increase the operating value of p_0. These effects of excessive jet pressure are due to partial loss of the unidirectional property of the vapor stream because of increased mean free path in the stream itself.

Recent studies[11] of rate of exhaustion as a function of the width of the annular opening show that: with an umbrella type nozzle (for mercury vapor), a maximum rate is obtained with an annular width of 0.55 cm (annular area of 7.4 cm²); a sloping umbrella (short divergent nozzle) gives a higher exhaust rate than a vertical one;[12] a long (5 to 20 cm) divergent nozzle makes use of the principle of the sloping nozzle and further aids in rectifying the vapor stream. Nozzles of the long, divergent design show an exhaust rate that increases as the width and area of the annular opening are increased to values of 1.6 cm and 33 cm², respectively, the limit of the studies.[13]

The long, divergent nozzle has been placed in a Langmuir type pump and, because of the reduced effective diameter of this type of chimney, a high exhaust rate has been obtained (175,000 $cm^3\ sec^{-1}$, with a nozzle length of 21 cm, a diameter of 7.6 cm, a divergence of 10°, and *n*-dibutylphthalate as the pump fluid[13]). The divergent type of nozzle gives remarkably high rates of exhaustion because of two factors: decreased p_0 or increased speed factor and decreased pump-head resistance. The latter factor only contributes to an increase in the pump speed.

A large effective annular opening may be obtained by using many small nozzles in parallel in place of a single large one. Sufficient space is left between the several nozzles for additional

[12] Holtzmark, Ramm and Westin, Rev. Sci. Inst. **8**, 90 (1937).

[13] Copley, Simpson, Tenney and Phipps, Rev. Sci. Inst. **6**, 265 (1935).

path of the gas. A nineteen-nozzle mercury pump built by Lauritsen[14] has an exhaust rate of 320,000 cm^3 sec^{-1} as measured at the pump-head at 10^{-4} mm-of-mercury. This pump is 11 in. in diameter and 27 in. high, excluding the boiler. Amdur[15] describes an oil pump having 10 jets in parallel with an exhaust rate of 250,000 cm^3 sec^{-1} at 10^{-4} mm-of-mercury. Divergent nozzles are used in these pumps.

The divergent type of nozzle has another advantage. A boiling liquid gives off vapor in spurts, and, in a pump, the spurts of vapor cause a lack of smoothness in the exhaust rate. With a divergent nozzle, an increased power may be supplied to the boiler, thus giving a rather high vapor pressure (excessively high for a short nozzle) at the constriction in the chimney, which results in smoother operation.[16]

Physical properties of the operating fluid determine certain features of the design of fast pumps; but, usually, a pump designed for one oil will operate with another oil or with mercury, and vice versa. In general, a short, wide, heated chimney is more important in oil pumps than in mercury pumps because of the relative importance of the temperature gradient along the vapor path. This is a consequence of the steeper curves of vapor pressure *versus* temperature for the oils. Since oils are more readily condensed than is mercury, a shorter condensing surface may be used; in some designs of oil pumps the water-cooled jacket is dispensed with, air currents being relied upon to cool the condensing walls. The vapor pressure of the oils at room temperature (assuming no volatile products of decomposed oil) is lower than that of mercury and a slightly wider annular opening may be used for a given speed factor. Also, because of the relative vapor pressures,[3] a freeze-out trap is indispensable with mercury, whereas a cold baffle[17] suffices with a good oil in a self-purifying type of pump.

[14] T. L. Ho, Rev. Sci. Inst. **3**, 133 (1932); Physics **2**, 386 (1932).

[15] I. Amdur, Rev. Sci. Inst. **7**, 395L (1936).

[16] Other methods of heating the fluid in the boiler have been devised to minimize "bumping" and to increase smoothness of operation; see, for example, L. Boddy, Rev. Sci. Inst. **5**, 278 (1934).

[17] An interesting spiral type of fast baffle is described by H. W. Edwards, Rev. Sci. Inst. **6**, 145 (1935).

Scientific Method and a Dilemma

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WHEN the subject matter of a science is simple, direct and of limited extent there is little need for a lengthy evaluation of its methods and aims, and its results are for the most part practical in character and quickly assimilated. But when a science becomes greatly complicated, very much more indirect in procedure, and of a surprising extent with ramifications in all directions, the need for a broader understanding of its method and logical basis, and even its aims, is at once apparent. However, along with this need the physicist is faced with a dilemma. Shall he sacrifice time in doing the actual work of his field in order to devote more time to evaluating the logical meaning of such work, or shall he, perhaps, sacrifice the logical meaning for the results?

The problem is a real and serious one. The increasing indirectness of the methods of physics and its greatly increased self-critical nature demand the former; at the same time the rapid expansion of the field and the many demands made upon the physicist would seem for several reasons to diminish the opportunity for the former and demand the latter. There is also, unfortunately, the added difficulty that quite often the individual who feels most at home in a physics laboratory or in a physics classroom does not feel comfortable in any realm in which the problems have a more philosophic character.

The latter difficulty is due in part at least to a misunderstanding which can be remedied, but the principal quandary in which the physicist finds himself cannot be so easily dealt with. Nevertheless, a little consideration forces us to recognize that no matter how remote from physics many more purely logical problems may seem, and no matter how much being a physicist may seem to preclude being a philosopher of science, such problems are being forced upon the physicist by the trend of modern physics. It is no longer a question as to whether or not he shall attend to such problems, but only as to what part of the logic of physics he should accept as his province.

In Newton's day there was no extended logical substructure to physical science. Physics was concerned mostly with direct perception and contained few hypotheses. But today the reverse is true. Hypotheses and abstractions are multiplying rapidly (in some directions almost extravagantly), and both old and new viewpoints need to be revalued. The teacher of physics especially should be more than a repeating dictionary and should have something more than an indefinite philosophic haze or a naïvely realistic attitude on which to base his views. Many teachers of physics, either in college or secondary school, may not have either the training or the aptitude to go far into scientific methodology, yet the complete exclusion of the logical basis of physics from the physics course of today must leave many comparatively dry bundles of bones.

A recent college physics text says, "The purpose of physics is to describe as accurately and clearly as possible the physical processes which go on in the world about us." This would at first seem to be a very objective aim which totally excludes the philosopher. But in the next sentence the author says, "To be truly scientific this must be done without bias or preconceptions of any kind." The philosopher who was apparently excluded in the first sentence hereupon turns an abrupt about-face and marches back into the picture again.

It is unnecessary further to belabor the point of the growing need of the physicist to interest himself in the philosophy of science. The number of recent books and articles on the subject, of which many have been written by physicists (particularly in England), bear witness to the fact. One thing is certain, however, the elaboration of the logical basis of physics and its interpretation must not be left to the professional philosopher who, with his age-long verbal muddles and his traditional lack of scientific training, is in some ways one of the last persons to pronounce upon the subject.

The traditional philosophic muddles, such as that of realism *versus* idealism, free-will *versus* determinism, and many other similar issues, are among the chief reasons for the physicist's frequent disgust with philosophy, and for the recent statement of a physicist at a conference on the philosophy of physics that, "Questions about a theory which do not affect its ability to predict experimental results correctly, seem to me quibbles about words rather than anything more substantial, and I am quite content to leave such questions to those who derive some satisfaction from them." This leaves the philosopher in the embarrassing situation of seeking satisfaction solely in quibbles (which he sometimes appears to do); but, more unfortunately, at the same time it would seem to put the philosopher of science into the same category. The philosopher by the same token might vent his ire on physics and assert that the physicist is often like a child playing with fire (or with pebbles on the seashore) and that he does not really understand what he is doing.

If the physicist does not care for such problems, he must at least recognize that there are legitimate philosophic problems concerned with science which are not properly described as quibbles and may not be directly concerned with the prediction of experimental results. And he should also recognize that philosophy like physics is rapidly casting off worn-out clothing and turning away from its traditional muddles toward the new land of science. An example in point is the attitude in logic as expressed in Dewey's recent book, *Logic, the Theory of Inquiry*,[1] in which the operational viewpoint derived from physical science is wholeheartedly adopted. Logic is therein shown to result directly from man's contact with nature and it is given a direction in keeping with the spirit of modern science.

[1] Henry Holt, 1938.

In what aspects of scientific philosophy should the teacher of physics interest himself? Professor Kemble of Harvard has said at a recent conference on the philosophy of science that the physicist's "one *semi-philosophic* concern must be to clarify fully the procedure whereby he passes from his sense perceptions to the world of his constructs and back again." But this apparently compact statement opens up a wide field, and it is a far more inclusive statement than at first appears. It obviously permits the physicist to analyze and clarify the logical structure of physical theory and its relation to experience. It permits him to analyze and clarify basic concepts and to study the meaning of the symbolism of physics. It permits him to ask the fundamental question of the relation of logic to physical inquiry. And it might also seem wisely to limit him to the things which he knows the most about. On the other hand, it would seem to limit his philosophic interest either to what goes on in his own head or to the region from his fingertips up to and including his head. It would seem to debar him from asking how he gets these sense perceptions, even though the quantum theory brings the observer into the experimental system, and also to debar him from seeking to know what in his experience is due to objects of the knowing process, and what is due to the process itself. It would apparently debar him from asking the meaning of physics as a science in relation to life in general, which is a philosophic concern of utmost practical importance. It would certainly debar him from inferring pleasant metaphysical opinions concerning the nature of reality and the universe as a whole unless these are permitted in the world of his constructs. It does not define what is permissible in that world. And it is not quite clear whether or not it would debar him from the morass of psychological theories of perception. But all of this may be taking too many liberties with a single compact statement. Perhaps it does show that no single statement can properly delimit the field of philosophic interest of the physicist. Yet to delimit the field, so that the physicist can get his bearings in it, is of pressing importance at the present time.

The customary feeling of unhappiness felt by some physicists upon being exposed to what are called philosophic problems, is due partly to a misunderstanding of what present-day philosophy aims to do and partly, perhaps, to a lack of familiarity with some of its terms. The overwhelming influence of science on modern philosophy can readily be seen if one considers the three grand divisions of philosophy—methodology, metaphysics and theory of value.[2] The first division is concerned largely with logic and scientific method, and as such is becoming more and more dependent upon (one is almost tempted to say a branch of) modern science. According to the logical positivists, and even to Mach and his phenomenalistic followers, all or a large part of metaphysics has no meaning and hence that subject apparently vanishes into thin air. When defined, however, as the study of (*a*) fundamental concepts and (*b*) cosmology, what is left is at once seen to belong solely to the sciences, though part (*a*) had better be classed with methodology. As for the third division, there is a growing feeling today that the theory of value should be much more closely related to the world in which we live, and that science should concern itself more with human values. Evidence of this is world-wide since a few years ago when the British Association opened its discussions to the social effects of science, and since, more recently, the American Association for the Advancement of Science has set up a Committee on the Improvement of Science in General Education and the International Council of Scientific Unions has set up a Committee on Science and Its Social Relations.

The demise of classical philosophy represented by its logic and its metaphysics, too often far removed from the real world of physical science, appears all the more violent when it is remembered that basic thinking now involves such concepts as space-time, quantum state, matrix, fundamental tensor, neutron, mesatron, etc. These can scarcely be dealt with except along accepted scientific paths by persons who have some training in this direction. Logical relations are likewise proportionately more complicated, and in order to deal with these it is necessary to have much more than the passing acquaintance

[2] See Montague, *Ways of Knowing* (Macmillan, 1928), p. 43.

which classical philosophy had with the simple scientific concepts of its day.

The name *philosophy of science* is a more or less indefinite term that covers many relations which involve the sciences, and of these, the logic of science (or in particular, the logic of physics) is only a part. To set an arbitrary limit to the interest of the physicist in such matters involves considerable risk, and the limit should in the last analysis depend upon the individual. Some individuals would by nature limit themselves to the logical analysis of the structure of such symbolic systems as relativity and wave mechanics, or perhaps to the logical analysis of the fundamental concepts of such systems and their relation to symbolic structures. To other individuals the operations of physics, such as those involved in observation, measurement, abstraction, analogy, etc., would be of special interest. The mere fact that certain philosophers and scientists have sought to demolish metaphysics would not keep some scientists from giving time to such questions as the expansion of the universe, the finitude of space, the one- or two-way nature of time, etc. These scientists probably would declare loudly that they were not idly speculating on metaphysical nothings but were attempting to draw valid conclusions from observed facts. No matter how we personally may feel about such types of problems, not one of them can be ruled out as falling outside the province of the scientist. In addition, there still remains that large body of problems concerned with the interpretation of physics in relation to science as a whole and to life in general. The error which the physicist often makes of isolating himself in his subject is no less a regrettable one because of the comfort he may enjoy in his splendid isolation. It matters little how much he may feel that he has really not isolated himself from the rest of the world but that the rest of the world is at fault in not trying harder to understand him. The time has passed when the scientist can afford to retire to his laboratory murmuring, "My job is to investigate; and it is no concern of mine what uses are made of my discoveries."

Professor Kemble's use of the term *semi-philosophic* is an interesting remnant of that natural caution with which physicists even yet hesitate to admit any wholly philosophic interests. However, it is hardly necessary to point out that the interests which he mentioned as semi-philosophic could scarcely be more philosophic. When a physicist concerns himself with the nature and meaning of explanation and description, he has momentarily turned philosopher. When he concerns himself with the analysis of the act of making a scientific observation, of the act of discovery, or of the meaning of symbols and such terms as *nature* and *reality*, *space*, *time*, *law* and *order*, *cause* and *effect*, he has become decidedly philosophic and he is no less so when he inquires into the basic concepts and logical structure of quantum mechanics. Even when he considers the symbolic relation $F=Ma$, and concerns himself with the concepts represented by these symbols, he is being a philosopher as much as a physicist and he might as well be honest enough to admit it. He should also be willing to learn from what philosophers have accomplished in the past in spite of their muddles. For example, some physicists are just now rediscovering much of what Hume said, as far back as our American revolution, about cause and effect.

Consider for a moment the term *force* and its use in some recent texts. To many physicists this term means something of utmost physical reality and fundamental importance—something by which the law of causation works. To others, the symbol for the term *force* may represent merely the numerical product of the mass of an object and its acceleration, and have no independent existence, or, as someone has said, it may merely be the nominative of the verb *to accelerate*. A recent popular text on general college physics translates a phrase in the statement of Newton's second law as "force creates momentum." This phrase has sad philosophic implications though it may possibly express Newton's view. Without sufficient explanation such a statement is unfair to the student today because it certainly does not express the modern view.

Another recent text says, "The force acting on a body *is proportional to the inertia of the body* and to the acceleration which is produced," (the italics are mine). It also contains the surprising statement that the "amount of this

inertia is a measure of the mass," whereas mass is usually taken to be the measure of inertia. Still another text gives the word *force* a Jekyll and Hyde character when it says, "If a body is free to fall, the same force is operating on the earth and on the falling body. This force acts upon both for the same time and they will meet with equal momenta. All forces have this dual nature." This statement may be contrasted with a common one, that forces always occur in pairs. And, of course, one must remember that in relativity theory forces, as such, either disappear altogether or receive a decidedly geometrical interpretation. In any case it may be well to recall Pearson's statement following the phenomenalism of Mach, that "Mass as the quantity of matter in a body, matter as that which perceptually moves, force as that which changes its motion, are solely and purely names which serve to cloak human ignorance." This does not mean that they may not be operationally useful.

Physics and the philosophy of physics cannot be separated by a sharp boundary. On the contrary, they are inextricably intertwined and interwoven, and the physicist of today is becoming more and more conscious of this fact. The decline of the mechanistic view of the universe is evidence of it. The development and use of new forms of symbolic logic give further evidence. Quite recently the growing relationship of the organic and inorganic worlds has been illustrated by studies such as those of crystalline forms which are apparently able to reproduce themselves. Thus the problems of biology and physics draw closer together and open up a new field for logical physics.

If one takes the realistic position that there is an external world independent of thought, one recognizes that scientific observation involves an object to be known, an observer who is the knower, and some intermediary process by which, through sense perception, the knower knows the object. This has long been recognized to involve such incompletely understood regions of physiology and psychology, sandwiched in between the logic and the physics of the process, that the opportunity for muddling and quibbling has been enormous. Yet, with the increasing indirectness of modern science, the question of this chain of events again comes to the front and even this field may open its doors to the onslaught of physics. An example in point is the recent work of Fletcher on auditory sensations.

It should not be too much to ask that the well-prepared teacher of physics know something of the phenomenalism of Mach; of the realism of Whitehead and Russell; of logical positivism, and of Wittgenstein and Carnap; and of many-valued logics. He should, of course, know something of the logical implications of relativity and the quantum theory and, especially, of the operational viewpoint and its limitations. He should know something of the changed aspect of older concepts, and he should know enough to avoid extremes of viewpoint unless there are clearly defined and satisfactory reasons.

As an illustration of what is perhaps a general feeling, mention may be made of the desire of a large majority of secondary school teachers in Illinois as reported by L. I. Bockstahler.[3] This desire was for more information as to how and where the principles of physics are applied in industry and daily life, and for more information in simple form about the recent developments and theories of physics together with their implications. It is nothing more nor less than the expression of a need for more meaning in physics, and for an evaluation of that meaning with reference to life itself. Neither of these demands can be avoided by the physicist, but in the last analysis the whole matter involves a philosophic, as well as what is commonly regarded as a scientific, attitude. These attitudes must ever become more and more mutually inclusive.

Brief List for General Reading

A. C. Benjamin, *An Introduction to the Philosophy of Science* (Macmillan, 1937).
P. W. Bridgman, *The Nature of Physical Theory* (Princeton Univ. Press, 1936).
R. Carnap, *The Unity of Science* (Kegan Paul, 1934).
C. E. M. Joad, *Philosophical Aspects of Modern Science* (Macmillan, 1932).
C. I. Lewis, "Alternative Systems of Logic," Monist **42**, Oct. 1932.
Karl Menger, "The New Logic," Phil. Sci. **4**, 299 (1937).
Karl Pearson, *Grammar of Science* (Black, ed. 3, 1911; Everyman's Library, 1937).
Bertrand Russell, *Analysis of Matter* (Harcourt Brace, 1927).

[3] Am. Phys. Teacher **6**, 43 (1938).

The Effectiveness of a Sound Motion Picture in College Physics

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THE motion picture is firmly established in our educational system. The city of Chicago[1] used 60,000 films in its public school system during the school year 1935–36. There appears to be ample experimental evidence for the claim that motion pictures: (1) produce better achievement in certain fields than other teaching devices;[2] (2) in some areas at least, produce better learning and longer retention;[3] (3) are effective in attitude building;[4] (4) may be used to increase class discussion;[5] (5) can promote good thinking;[6] (6) provide new and rich experiences; animated drawings and stop-time lapse photography make possible the viewing of scenes and activities otherwise impossible under school conditions.

Most of these findings have been made with elementary school pupils. There has been little or no study of the learning produced by educational films in college physics, due primarily to the seeming complexity and elusiveness of learning processes.[7]

The Problem

Early in 1937 the Erpi Pictures Consultants released a sound film entitled *Electrodynamics*. No member of the writer's college physics classes had seen the film or studied electricity in college. Consequently, it gave opportunity to study specifically: (1) the learning produced by two showings of the film; and (2) the effect of an additional stimulus to learning in the form of a study sheet to be used during the class hour when the film was shown.

The effectiveness of the two methods of presentation was evaluated as follows:

(1) The acquisition of factual material;
(2) The ability to transfer new learning to specific new situations not used in the film;
(3) Learning differences especially characteristic of the various ability levels;
(4) The differences in the learning of specific items produced by the two methods.

Experimental Technic

(1) The writer and his assistant studied the film very carefully during several showings at normal and slow speeds. The principles illustrated by the film were listed, and 37 multiple choice test items covering the factual material presented in the film were built around the more important principles.

(2) A second test of 12 questions was constructed by using the principles in situations quite different from those in the film. It was made to measure the student's ability to usefully transfer information to a new situation.

(3) A study sheet was prepared listing 23 important things to be watched for in the film and suggesting questions whose answers could be found in the pictures. This sheet was studied for 5 min before the first showing and for about 10 min between showings by the students in Section *A* only.[8]

[1] *American Council on Education*, "Motion Pictures in Education," Series II, Vol. I, No. 2, p. 5.
[2] Knowlton and Tilton, *Motion Pictures in History Teaching*, p. 90.
[3] P. J. Rulon, *The Sound Motion Picture in Science Teaching*, pp. 87–88.
[4] Peterson and Thurstone, *Motion Pictures and the Social Attitudes of Children*, p. 66.
[5] Reference 2, p. 92.
[6] Reference 3, p. 104; H. C. Davis, *Specific Values of Educational Films Used as Supplementary Aids in Instruction*, p. 110; Wood and Freeman, *Motion Pictures in the Classroom*, p. 204.
[7] A maker of educational films recently told the writer that he had attempted to study the learning accomplished by two showings of one of his first films. He examined the results, decided the problem was so complex in terms of what he had done to investigate it that the data obtained were worthless, and abandoned the investigation.

[8] The following are samples of the material used in the study.

Fact-finding items

A battery consists of (1) two metals in contact, (2) dissimilar metals joined by a moist material, (3) anything having two electrodes, (4) two pieces of the same metal in a cup of liquid, (5) any source of current.

A helical coil of wire in which a current exists (1) has a north magnetic pole at one end, (2) has north magnetic poles at both ends, (3) does not have a magnetic field inside the coil, (4) has magnetic poles only if it has an iron core, (5) has magnetic poles only if the current is changing.

Transfer items

A small magnet placed near a straight wire containing a current would (1) tend to point toward the wire, (2) tend to be repelled from the wire, (3) travel around the wire in

TABLE I. *Matched groups on pre-test data and gains.**

SECTION	NO. OF STUDENTS	PRE-TEST A. M.	PRE-TEST S. D.	POST-TEST A. M.	POST-TEST S. D.	GAIN, PRE-POST	PRE- *vs.* POST-TEST CORRELATION
A	56	19.8	7.38	33.7	8.0	13.9	.74±.04
B	56	19.8	7.38	32.4	6.6	12.6	.67±.05

A. M. denotes *arithmetic mean*; S. D., *standard deviation*.
* The *coefficient of correlation* is a quantitative expression of the relationship between two variables. Its range is from 0, indicating no relationship, to 1.00, indicating perfection relationship. The sign of the coefficient is positive if the relationship is direct, and negative if the relationship is inverse.

TABLE II. *Matched groups on placement data and gains.*

SECTION	NO. OF STUDENTS	PLACEMENT A. M.	PLACEMENT S. D.	GAIN, WHOLE GROUP, COL. 7, TABLE I	GAIN, PART GROUP—52 STUDENTS
A	52	118.1	22.3	13.9	14.5
B	54	120.3	23.6	12.6	12.8

(4) On the Friday preceding the week of the experiment the project was explained to two sections in College Physics. The students were told that there would be an inventory pre-test on Monday, a double showing of the sound film on Wednesday, and a learning test on Friday. They were asked to participate on a voluntary basis only, and those who volunteered pledged that they would do their best on both examinations, and that they would undertake no learning project in college physics during the next week other than the regular laboratory work which had little in common with the film.

On Wednesday, 5 min before the film was run, Section *A* was given the study sheet, which carried the instructions: "While you are watching the film that will soon be shown, look carefully for the following items and for answers to the following questions."

a circle, (4) tend to align itself so as to be tangent to a circle which has the wire as a center, (5) be pulled in the direction of the current.

The electrostatic charges carried along on a rapidly moving machinery belt (1) have no associated magnetic fields, (2) will have an associated magnetic field, (3) can in no sense be considered to be an electric current, (4) have nothing in common with current electricity, (5) would be quite unaffected by a transverse magnetic field.

Study sheet

While you are watching the film that will soon be shown, look carefully for the following items and for answers to the following questions: Just how were the frog's legs hung and what made them jerk? What constitutes a battery? When does a coil of wire act like a magnet? When does the core in a coil attract iron filings? What does temperature do to a magnetic material?

The film was shown twice and, during the 10-min intermission, the students were asked to examine the study sheet again to see if they had observed all of the items listed. Section *B* saw the film twice, but without the study sheet. The students were permitted discussion in the intermission while the film was being rewound.

RESULTS

Fifty-six students from Section *A* and 75 from Section *B* volunteered to take part. With the pre-test scores used as a basis for matching, 56 Section-*B* students were found who matched the 56 in Section *A* very closely. The data in Table I show how closely the two groups were matched.

The two sections were also compared on the basis of the scores made on the *Physics Aptitude Test*, Iowa Placement Examination Series, Form A, which was given at the beginning of the college year (Table II). Of the 56 students in each group, 52 of Section *A* and 54 of Section *B* had taken the placement examination. The remaining six students (4 in *A* and 2 in *B*) were, on the average, poor students, but the two from *B* were better than the four from *A*. Adding four poor students to an already inferior Section *A* makes Section *B* distinctly superior when considered on the basis of the placement examination. The data in Table I show that Section *A* made a 10-percent larger gain than Section *B*. The difference in gain is 1.3, with a probable error of 0.43. The critical ratio is 3.0, which means that the chances are 96 out of 100 that the gain made by Section *A* is actual and significant rather than a chance error due to sampling. If the data in Table II are used as a basis for matching, Section *A* made about 16 percent larger gain than Section *B*. However, all conclusions drawn in this paper are based on the matching indicated in Table I, which involves the smaller gain. Therefore, it may be assumed that there will be a slight underestimation of the experimental results.

TABLE III. *Test data and correlation coefficients for the two groups by quarters.*

QUARTILES	SECTION	PRE-TEST RANGE	POST-TEST RANGE	PRE-TEST A. M.	PRE-TEST S. D.	POST-TEST A. M.	POST-TEST S. D.	PRE- vs. POST-TEST CORRELATION
I	*A*	1–16	8–37	10.3	4.8	26.5	9.2	.51± .13
I	*B*	2–15	14–39	10.7	3.7	27.0	7.1	.18± .18
II	*A*	16–19	25–40	17.3	1.0	31.9	4.7	.32± .16
II	*B*	16–19	27–37	17.1	.9	31.4	3.3	.11± .18
III	*A*	20–25	23–42	22.1	1.6	36.2	4.9	.17± .18
III	*B*	20–25	27–38	22.0	1.7	32.8	3.5	.42± .15
IV	*A*	24–34	35–47	28.9	2.6	40.6	3.6	.18± .18
IV	*B*	25–36	33–45	29.5	3.4	39.3	3.1	.23± .17

Table III shows the test results and the correlation coefficients between the pre- and post-tests when analyzed by quarters.[9] Fig. 1 shows graphically the percentage gain in achievement for the four quartiles of each section. The percentage gain made by Section *A*, which had the study sheet, is greater for every quarter than that made by Section *B*.

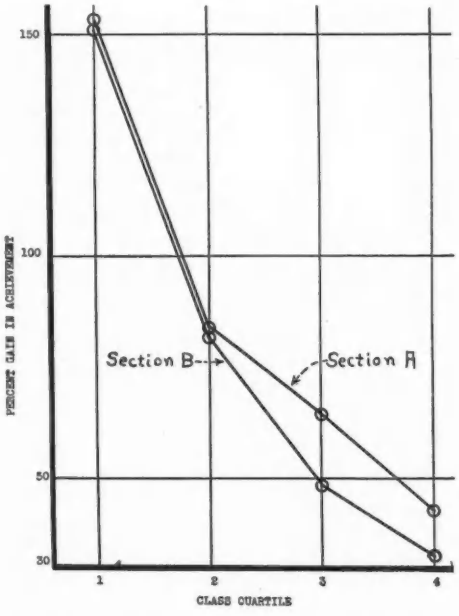

FIG. 1. Percentage gain in achievement for the four quartiles of each section.

[9] A *quarter* includes 25 percent of the cases. Thus, the first quarter, Q^1, is composed of the lowest quarter of students; Q^2, the next higher, 25 percent; etc.

Figure 2 shows the correlation coefficients between the pre- and post-tests for each quarter graphed with respect to quarters. The number of students in each quarter is small and consequently the probable errors for these coefficients are large. Only three of the eight coefficients are high enough to have statistical value when taken alone, but the curves when studied in connection with the standard deviations given in Table III are thought to be significant. The students in the lowest quarter who had the study aid, learned more as a group and tended in the post-test to maintain the same rank or position within the group as they had on the pre-test; with help to get started, each one got something done that was more or less consistent with his aptitude. The next to the lowest quarter in Section *A* did the same type of thing but to a lesser degree. The members of the two lowest quarters in Section *B* appeared to learn as individuals—not as a group, as was the case with Section *A*. There was much shifting of the individual positions within the group on the post-test. Just the reverse is true for the two high quarters in which the individuals having aid learned considerably more as a group and also changed considerably in position within the group. This leads to the conclusion, poorly founded, but important if true, that *some students are more capable of making use of aid than others.*

TABLE IV. *Comparison of post-tests.*

	SEC. *A*		SEC. *B*	
	FACT	TRANSFER	FACT	TRANSFER
Average	27.9	5.8	27.4	5.2
S.D.	6.1	2.5	4.8	2.2
Correlation		.61±.06		.41±.07

Table IV shows the two post-tests, fact and transfer, compared. *The section having the study sheet was only 2 percent superior in gathering facts, but 12 percent superior in the ability to transfer and apply the facts to a new situation.* The larger standard deviation for Section *A*, on both the fact and transfer tests, indicates that the study aid created a variability in both directions in that section which does not appear in Section *B*; that is, the study sheet was an aid to the better students and a hindrance to the poorer ones. The substantially higher correlation between post-test fact and post-test transfer for Section *A* indicates that there is relatively high consistency between the number of facts known and the ability to use them in a new situation. The students in *A* were more able to make transfers than those in *B*. This is a little surprising in view of the fact that Section *A* was little, if at all, superior in the ability to gather facts. The interpretation in connection with the other data is that members of Section *A were more sure of the facts and could make better use of them in new situations.*

Table V is presented in full because of its great significance. It shows how the two matched groups functioned in learning from the film on the various items in the examination. The second column gives the number of students in Section *A* who did not know the facts presented in the item before they saw the film; the third column, the percentage of the students who learned the answer to the item by seeing the film. The last two columns give similar information for Section *B*.

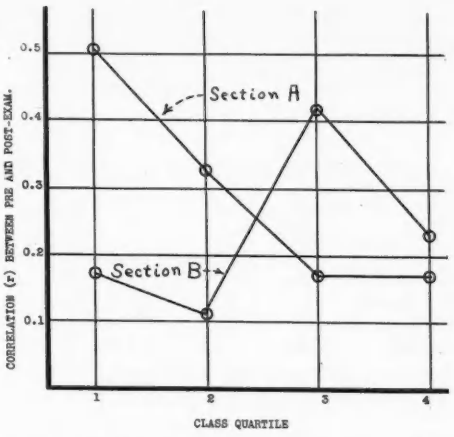

FIG. 2. Correlation coefficients between pre- and post-tests for each quarter *vs.* quarters.

Below are listed facts and generalizations, grouped according to the teaching effectiveness of the film in the learning situation described. The learning is here defined as being *very superior* when 85 to 100 percent of those who failed the item on the pre-test answered it correctly on the

TABLE V. *Tabulation of test results by items.*

Test Item	Sec. *A* No. Who Failed Pre-test	Sec. *A* Percent Who Learned From Film	Sec. *B* No. Who Failed Pre-test	Sec. *B* Percent Who Learned From Film	Test Item	Sec. *A* No. Who Failed Pre-test	Sec. *A* Percent Who Learned From Film	Sec. *B* No. Who Failed Pre-test	Sec. *B* Percent Who Learned From Film
1	25	88.0	26	92.4	26*	35	80	29	75.9
2*	25	−8.0	27	−29.6	27*	9	88.9	24	79.2
3*	21	81.0	18	72.3	28*	39	33.3	47	34.1
4*	15	60.0	10	30.0	29*	25	92	22	91
5*	35	86.8	35	80	30*	52	42.3	45	33.3
6*	22	100.0	26	96.3	31*	32	84.4	25	76
7*	42	64.3	29	58.7	32	28	60.8	23	87
8	16	87.6	17	100.0	34*	27	63	29	44.9
9	19	68.5	16	50	35	26	42.3	34	58.8
10	18	89.0	12	100	36*	50	76	52	33.3
11	26	56.0	20	70	37	34	29.4	33	21.2
12	13	77.0	13	100	38	24	0	31	29
13	18	72.3	16	93.8	39	42	71.5	36	47.3
14*	5	80.0	8	100	40	24	33.3	32	34.4
15	37	51.4	39	48.8	41	40	57.5	47	72.3
16*	14	85.8	15	80	42	35	20	47	46.8
17*	11	90.8	19	52.7	43	20	−5	14	7.1
18*	31	80.6	41	53.7	44	11	81.9	8	75
19	22	50.0	22	81.9	45	37	48.7	45	31.1
20	7	28.6	8	37.5	46	52	−1.9	56	−5.4
21*	5	60	4	50	47	46	34.8	50	10
22*	24	87.5	17	88.3	48	31	51.7	42	45.3
23	25	72	34	85.3	49	49	40.8	46	65.2
25*	35	62.8	36	58.3					

Items 24 and 33 were omitted from the study because of printing errors.
* See footnote 10.

post-test; *superior*, for 70 to 85 percent new learning; *poor*, for 50 to 70 percent new learning; and *very poor* for learning below 50 percent.

Very Superior Learning

Galvani's discovery came from an observation made in an accidental situation.

When the current in a wire is stopped, the magnetic lines of force collapse into the wire.

The magnetic field strength at the end of a current-carrying solenoid depends directly on the number of turns in the solenoid.

A long straight wire in which electricity is flowing is surrounded by circular magnetic lines of force.

A soft iron rod placed inside a coil of wire will strongly attract iron filings when a current exists in the coil.

When the magnetic lines of force about a wire expand it is because the current in the wire is increasing.

Iron ceases to be attracted by magnets when heated to a high temperature.

A generator may consist of a loop of wire rotating in a magnetic field.

A current induced by a changing magnetic field through a coil varies with the number of turns in the coil.

Superior Learning

A cell may consist of dissimilar metals joined by any moist material.

The number of magnetic lines of force around a wire varies with the current in the wire.

Two of the widely varied uses of the electromagnet are to lift weight and to ring door bells.

Magnetism of permanent magnets is explained by saying that the magnetic fields of the molecular currents reinforce one another.

If a wire is wound into a closed coil, electricity is caused to flow in it when magnetic lines of force from a magnet cut the coil.

If a coil connected to a galvanometer has an electromagnet suddenly withdrawn from it, the galvanometer indicates a current only when the electromagnet is in motion.

When two coils *A* and *B* are near each other, and a steady current is in *A*, a current will exist in *B* when it is moved so as to cut the magnetic lines of force of *A*.

The purpose of the iron core in a transformer is to cause more magnetic lines of force to link the primary and secondary coils.

Poor Learning

A helical coil of wire in which electricity is flowing has a north-seeking magnetic pole at one end.

The strength of the magnetic pole at the end of a coil varies with the current in the coil.

The magnetic field of a stationary wire carrying a steady current remains stationary in space.

An electromagnet is made by placing a piece of iron inside a coil of wire carrying a current.

When we thrust a magnet into a coil, the ends of which are connected to a galvanometer, the galvanometer indicates a current while the magnet is moving into the coil but no current when the magnet is stopped.

Very Poor Learning

An electric current involves electric charges in motion.

If a bar of unmagnetized soft iron is placed within a solenoid and then a unidirectional current is sent through the solenoid, the bar becomes a magnet even though the magnetizing field is very small.

If an unmagnetized soft iron bar is held in a magnetic field, the molecules of the bar line up so that the bar becomes magnetized.

A large current exists in the secondary coil of a transformer when the current in the primary coil is changing rapidly.

If a steady current in the primary coil of a transformer is suddenly broken, the current in the secondary coil will consist of a single pulse.

Electric power is transmitted long distances at high voltage because that is the most economical way to do it.

To have an electric current between two points it is necessary and sufficient that there be both a difference of potential between the two points and a supply of carriers of one sort or another.

One item on the test, "Galvani observed that a frog's leg quivered peculiarly when it touched simultaneously two dissimilar metals which were joined at the other end," gave the very unusual result that fewer students were able to answer it correctly after they had seen the film than before. This was true for both sections, although the study sheet carried the item: "How were the frog's legs hung and what made them jerk?" In this instance the film presentation was confusing, tending to create a misconception. The items listed under "Poor learning" and "Very poor learning" also give clues to portions of the film which did not provide proper instruction.

In order to render the study sheet effective in the short time available for its use, it was thought necessary to make the items short and to the point. They were aimed directly at specific principles or facts presented by the film and inventoried by the fact-finding test. Of the 37 items on the factual test, 21 had study-sheet items aimed directly at them.[10] Section *A*, which

[10] These are the 21 items starred in Table V. To illustrate this point, the study sheet carried the question, "What was Oersted's discovery," while test item No. 36 was: "The man who discovered that an electric current was accompanied by magnetic lines of force was (1) Faraday, (2) Oersted, (3) Galvani, (4) Rowland, (5) Franklin. Table V shows 76 percent learning in Section *A* and 33 percent learning in Section *B*.

TABLE VI. *Learning in areas toward which study-sheet items were directed.*

		No. of Such Items	No. of These Same Items At Which a Study Sheet Item Was Directed	No. of Items At Which No Study Sheet Item Was Directed
Learning in *A* as compared to that in *B*	Very superior	2	2	0
	Superior	4	3	1
	Considerably more	4	3	1
	Noticeably more	9	9	0
Learning in *B* as compared to that in *A*	Very superior	1	0	1
	Superior	2	0	2
	Considerably more	6	1	5
	Noticeably more	3	0	3

had the study sheet, showed appreciably better achievement than did Section *B* on 17 of these 21 test items. Section *B* was better on 1 item and the learning was the same in both sections for 3 items. On the 14 remaining items (2 were discarded because of faulty wording or printing errors), Section *B* showed appreciably better learning on 11, one was a tie, and Section *A* excelled on 2. Table VI gives in summary form the comparable learning in the two sections of the test items at which study items were directed and at which study items were not directed. From this it is clear that *the study sheet gave material aid in learning those facts and principles to which specific attention was called but directed attention away from other items presented by the film.*

It is of further interest to note that the aid given by suggestion on the study sheet appears to function, in some cases at least, only for the brightest students. Test item No. 7, "A helical coil of wire in which a steady current exists has a north magnetic pole at one end," referred to a part of the picture to which attention had been directed by the study item, "When does a coil of wire act like a magnet?" The validity of the item for Section *A* is so much higher than for Section *B* that the increased learning in *A* appears to have been done almost entirely by the very best students. Other items appear to function in the same way.

TABLE VII. *A study of transfer item No. 4.*

No. Getting	Successful on No. 4	Not Successful on No. 4	Success-Ratio
4 fact items: 63	50	13	3.85
3 fact items: 29	18	11	1.63
2 fact items: 9	5	4	1.25
1 fact items: 0	0	0	—
0 fact items: 3	1	2	0.5

The ability to transfer facts and principles to situations different from those in which the original learning occurred and to use successfully those facts and principles in the new situations is one of the most esteemed and elusive values in education. Some light is thrown here on this ability. The transfer test contained 12 items. Facts used in these items were cast into situations different from those in which the facts were learned in the film. For example (Table VII), the facts used in item No. 4 in the transfer test were inventoried in 4 of the fact-items. Of the 63 students who were successful on the post-test on all 4 fact-items pertaining to this situation, 50 made the transfer and 13 did not. Twenty-nine students were successful in getting 3 of the 4 fact-items and 18 of these successfully made the transfer.

A study of all of the success-ratios for the 12 transfer items showed only 5 instances where students who knew fewer facts were apparently more successful in effecting the transfer. However, these reversals involve such a small number of students that, out of 1344 cases, the shifting of only 8 would clear the 5 reversals in the success-ratios mentioned. Here we have excellent evidence that *the more facts one knows about the principles applicable to a new situation the greater is the probability that he will make a successful application.*

Summary and Conclusions

1. A technic was set up for the evaluation of the effectiveness of a motion picture film.

2. Within the limits of the present experiment it has

been shown that a film can be given greater teaching effectiveness by the simultaneous use of a study sheet.

3. Such a study sheet must be prepared with great care because it directs attention toward certain areas and away from others.

4. The study sheet had its greatest effectiveness for the students in the next to the highest quarter.

5. There is unmistakable evidence that the students in the lowest quarter were confused by the study sheet. There is a distinct optimum value for the amount of help a student can usefully consume. More than that adds confusion instead of clarity.

6. The teaching effectiveness of the film as a whole is high. The concepts having to do with magnetic field strength and its proportionality to the current producing it, the function of iron cores inside coils, the loss of magnetic properties of iron at high temperature, the basic definition of a cell and the simplest elemental facts about induced emf's were well taught.

Concepts similar to, "a current-carrying helical coil without a core behaves like a magnet," "electricity is atomic in nature," "magnetic properties of iron are traced to its molecules," "difference of potential between two points and a supply of electrical carriers are necessary and sufficient to produce an electric current," and the phase relationships of the currents in a transformer were poorly taught. The item, the "frog's leg quivered when it simultaneously touched two connected dissimilar metals," was so badly taught that some students suggested that the picture presentation was faked. When so much labor and money is expended in producing a film, it would seem highly profitable to subject it to a teaching test before it is released. Some of the teaching weaknesses could be easily remedied.

7. Some students are more able to use aid than others (a tentative conclusion).

8. There is evidence that the greater the "sureness" an individual has about a fact or group of facts, the more likely he is to use it in a transfer situation.

9. The students who participated in this study were enthusiastic about the film.

The author wishes to express his appreciation to Dr. D. D. Feder, now at the University of Illinois, for his critical assistance in making the study.

Edme Mariotte (c. 1620–1684)

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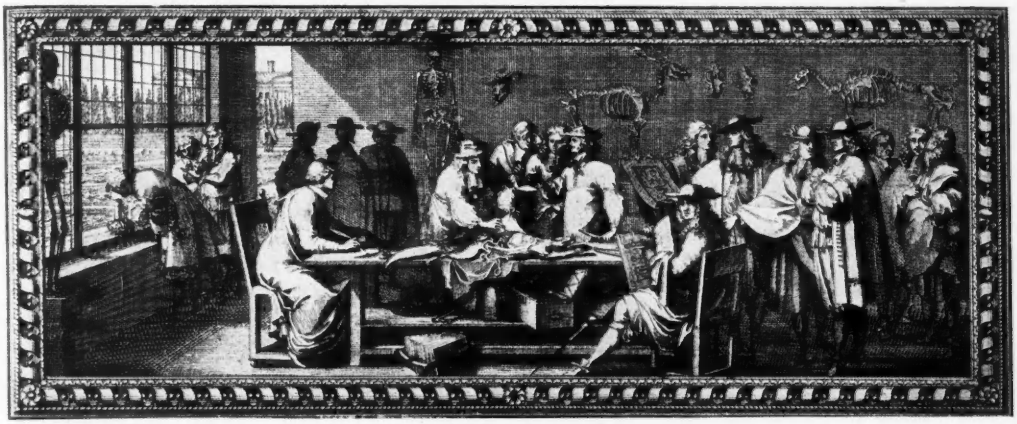
IN 1854 Thomas Carlyle wrote to David Laing in Edinburgh as follows:

> First of all, then, I have to tell you, as a fact of personal experience, that in all my poor Historical investigations it has been, and always is, one of the most primary wants to procure a bodily likeness of the personage inquired after; a good *Portrait* if such exists; failing that, even an indifferent if sincere one. In short, *any* representation, made by a faithful human creature, of that Face and Figure, which *he* saw with his eyes, and which I can never see with mine, is now valuable to me, and much better than none at all. This, which is my own deep experience, I believe to be, in a deeper or less deep degree, the universal one; and that every student and reader of History, who strives earnestly to conceive for himself what manner of Fact and *Man* this or the other vague Historical *Name* can have been, will, as the first and directest indication of all, search eagerly for a Portrait, for all the reasonable Portraits there are; and never rest till he has made out, if possible, what the man's natural face was like. Often I have found a Portrait superior in real instruction to half-a-dozen written "Biographies," as Biographies are written; or rather, let me say, I have found that the Portrait was as a small lighted *candle* by which the Biographies could for the first time be *read*, and some human interpretation be made of them. . . .

The purpose of this paper is to point out and to reproduce a possible portrait of the seventeenth-century French physicist, Edme Mariotte (*c.* 1620–1684), who, though overshadowed by his associate, Christiaan Huygens (1629–1695), and anticipated in his work on the gas laws by his contemporary, Robert Boyle (1627–1691), merits a higher rating as a scientist than is usually given him (by English writers at any rate), not only because of his many original investigations, but also because he was the first physicist in France to recognize fully the value of the experimental method. As Ludwig Darmstaedter has said:

> We owe [to such men] not only a careful reading of their work but also a study of their lives and characters so that they may appear to us as real personages. We can then better understand how they came to undertake and accomplish their tasks and



The Académie Royale des Sciences at work in the laboratory in the Royal Library, Paris, 1671. EDME MARIOTTE is the tall figure in skullcap and spectacles standing in the center of the picture. From a vignette by SÉBASTIEN LE CLERC in *Memoires pour servir a l'histoire naturelle des Animaux* (Paris, Imprimerie Royale, 1681).

appreciate in what way their accomplishments reacted in determining the course of their careers.

Unfortunately, however, practically nothing is known about MARIOTTE's life;[1] even the date and place of his birth are uncertain. We are therefore forced to judge him and to reconstruct his personality solely from his writings. In these, as CONDORCET has pointed out, "He displayed an upright and disinterested love of truth excelled by few investigators." No one can read his published works[2] without realizing that they were written by a gifted experimenter and a man of fine spirit.[3] It was with great pleasure, therefore, that I found, in the splendid engravings executed by SÉBASTIEN LE CLERC for the early publications of the Académie Royale des Sciences,[4] a vignette in which MARIOTTE is clearly portrayed.

Several of the early publications of the French Academy of Science were sumptuously produced by the royal printer and distributed as personal gifts by LOUIS XIV. Each of these large folio volumes is introduced by a magnificent vignette, 9.5×14 in. in size, showing the members of the Academy at work. The one from the *Memoires pour servir a l'histoire naturelle des Animaux* (Paris, Imprimerie Royale, 1671) is here repro-

[1] The known facts regarding Mariotte's life, together with discussions and appraisals of his scientific contributions, will be found in the following books and articles:
M. J. A. N. C. de Condorcet, "Éloge de Mariotte," in *Éloges des Académiciens de l'Académie Royale des Sciences* (Paris, 1773).
E. Merlieux, "Edme Mariotte," in Hoefer's *Nouvelle Biographie Générale* (Paris, 1863), Vol. 33, pp. 798–806.
L. Darmstaedter, "The Life of Edme Mariotte," J. Chem. Ed. **4**, 320 (1927).
P. Lenard, *Great Men of Science* (Macmillan, 1933), pp. 64–66.
The New Calendar of Great Men, ed. by F. Harrison, S. H. Swinny and F. S. Marvin (Macmillan, 1920), pp. 436–437.

[2] The *Oeuvres de M. Mariotte* were published at Leiden in 1717, with second editions at Paris and The Hague in 1740. All of Mariotte's known works will be found in these two volumes. They are:
Traité de la Percussion ou Choc des Corps, dans lequel les principales Régles du mouvement sont expliquées & demontrées par leurs véritables causes.
Essais de Physique, ou Mémoires pour servir à la science des choses naturelles: (i) *De la Végétation des Plantes;* (ii) *De la Nature de l'Air;* (iii) *Du Chaud et du Froid;* (iv) *De la Nature des Couleurs.*
Traité du Mouvement des Eaux et des autres Corps fluides.
Régles pour les Jets d'Eau.
Nouvelle Découverte touchant la Vûë, contenue en plusieurs Lettres écrites par Messrs. Mariotte, Pecquet & Perrault.
Traité du Nivellement, avec la Description de quelques niveau nouvellement inventés par Mr. Mariotte.
Traité du Mouvement des Pendules.
Expériences touchant les Couleurs et la Congélation de l'Eau.
Essai de Logique, contenant les Principes des Sciences, et la manière de s'en servir pour faire de bons raisonnemens.
The *Traité du Nivellement* was translated into Italian (1675) and the *Traité du Mouvement des Eaux et des autres Corps fluides* into Italian (1765) and into English by J. T. Desaguliers (London, 1718). The *Essais de la Nature de l'Air et de la Végétation des Plantes* and the *Nouvelle Découverte touchant la Vûë* were reprinted in 1923 by Gauthier-Villars in the series "Les Maîtres de la Pensée Scientifique."

[3] See, however, the *Note on a Singular Passage in the "Principia"* by P. G. Tait (Proc. Roy. Soc. Edin., Jan. 19, 1885) which is reprinted as Appendix IV of his *Properties of Matter* (Edinburgh, 1885).

[4] See "Reproductions of Prints, Drawings and Paintings of Interest in the History of Physics," No. 7, which appears elsewhere in this issue.

An enlargement of the central group in the vignette. Reading from left to right the figures may be identified as Louis Gayant, Edme Mariotte, Claude Perrault and Jean Pecquet.

duced. The human figures shown are clearly portraits.[5] Thus, the figure standing beside the open window and examining a small round object with a large lens is Huygens and the hatless figure with long curls in the group of four in the center of the print is Claude Perrault (1613–1688). The figures in broad-brimmed hats are clearly visiting gentlemen from the court and none of them need concern us here except perhaps the second from the right, who is Jean Baptiste Colbert (1619–1683), Louis XIV's minister and the man responsible for the Academy's founding and for its support. These three identifications can be confirmed by comparison with well-known portraits. The remaining four of the five figures in the center of the room carrying on and discussing the dissection and recording the results can also be identified with considerable certainty, for the five members of the Academy most active in anatomical work are well known. They were Perrault, Mariotte, Jean Pecquet (1622–1674), the discoverer of the thoracic duct and the circulation of the blood in the foetus, Jean-Baptiste Duhamel (1624–1706), the Secretary of the Academy, and Louis Gayant (d. 1673). Of these, Mariotte and Duhamel were ecclesiastics and it should be possible to distinguish them in any group by their clerical garb. There can be little question, therefore, that the figure seated at the table making notes is the Secretary, Duhamel, and that *the tall, rather gaunt figure in calotte and spectacles standing in almost the exact center of the print is* Mariotte. The other two figures (in fur-rimmed hats) may then be identified as Gayant (dissecting) and Pecquet (at the right), as these two, with Perrault, made practically all of the Academy's dissections. For the sake of completeness, it should perhaps be stated also that, in the article in *Osiris*,[5] the third figure from the right (also wearing a calotte) is identified as the astronomer, Jean Picard (1620–1682), and guesses are made that the member beside him is the mathematician, Pierre de Carcavi (d. 1684), that the man displaying the anatomical chart is Nicolas Marchant (d. 1678), and that the figure beside Huygens is Jean Richer (1630–1696), who led the famous astronomical expedition to Cayenne on which the important observation was made that the period of the seconds-pendulum in Cayenne was not the same as in Paris.

If these identifications are correct, this engraving is of the greatest interest historically for it gives us what are apparently the only likenesses we possess of three of the most famous scientists of the seventeenth century, Mariotte, Pecquet and Picard, as well as of several others who are less famous, and it shows them at work in the laboratory where much of their best work was done. It is of especial interest to the physicist, not only because it affords a much needed likeness of Mariotte, the resourceful experimentalist who insisted upon experiment in addition to observation even in anatomical studies, but also because it shows him in the midst of one of the arguments with Perrault and Pecquet out of which came results such as the discovery of the "blind spot" in the eye and the beginnings of a theory of vision.

[5] See "The Early Days of the Académie des Sciences as Portrayed in the Engravings of Sébastien Le Clerc," Osiris, in print.

No one can be really master of any science unless he studies its special history, which again is bound up with the general history of humanity.—A. Comte.

The Simple Harmonic Vibrations of a Stretched Rectangular Membrane

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SINCE a stretched membrane may be treated as a net of stretched strings, finding the normal modes of vibration of a membrane is not essentially more difficult than solving the problem of the stretched wire by the method which the writer previously discussed under the title, "An Elementary Treatment of Vibrating Strings."[1] Any of the ordinary methods for determining the normal modes of vibration for the membrane involve the solution of a partial differential equation and, hence, are available only to students who have a strong mathematical background. It is thus interesting to notice that the essential features of the behavior of a vibrating membrane can be deduced from principles familiar to the student of elementary physics and by the use of algebra which is not very difficult.

The problem to be solved is that of finding all of the possible simple harmonic standing waves for a uniform membrane of surface density σ gm/cm^2 which is stretched uniformly with a force of T dyne/cm on a rigid rectangular boundary. We shall follow the usual custom and neglect the weight of the membrane. If now we use a Cartesian coordinate system in which the X and Y axes coincide with two edges of the membrane, the z coordinates of the membrane will represent displacements from the equilibrium position. For simplicity we first take up the problem of a square membrane of length L cm on each edge. Following the method of the paper cited, we shall approach the solution of our problem through the simplification introduced, by considering the mass concentrated at a number of discrete points that are joined in both the X and the Y directions by a set of weightless strings all under the same stretching force.

Case I.—The first approximation is obtained by considering the entire mass of the membrane, $\sigma L^2 = M$, concentrated at the center of the membrane, and joined to the four edges by light strings each of length $L/2$ and each stretched by a force of TL dynes. If the displacement of the mass at right angles to the plane of the boundary is small compared with $L/2$, the restoring force F acting upon the mass will be $8Tz$, and the mass, if released, will execute simple harmonic motion of frequency f_{11} given by

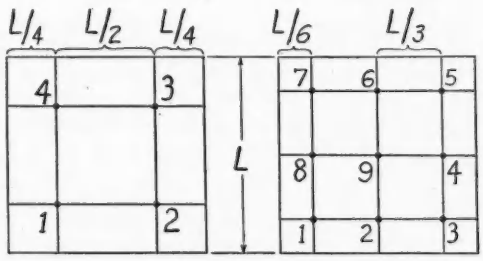
$$f_{11} = (F/zM)^{\frac{1}{2}}/2\pi = (8T/\sigma L^2)^{\frac{1}{2}}/2\pi = (2T/\sigma)^{\frac{1}{2}}/\pi L = 0.45K,$$

where K denotes $(T/\sigma)^{\frac{1}{2}}/L$, a quantity common to all of our expressions for frequency. The expression for the fundamental frequency of a uniform membrane, when obtained by advanced methods, is

$$f_{11} = (T/2\sigma)^{\frac{1}{2}}/L = 0.707K.$$

The ratio of the approximate result obtained from the simplified representation to the exact result is therefore $2/\pi$, precisely as in the similar treatment of the vibrating string.[1] The single frequency which we have obtained is the only one that this relatively crude model is capable of yielding.

Case II.—For a second approximation, we divide the membrane into four equal parts, each of mass $\sigma L/4$ gm, which are then assumed to be located at distances $L/4$ cm from the edges as shown in Fig. 1. For the purpose of simulating the membrane, the force stretching each string of the net is set equal to $TL/2$ dynes. We now ask how the particles may be displaced so that all will execute simple harmonic motion of the



FIGS. 1 and 2.

[1] P. L. Copeland, Am. Phys. Teacher **5**, 193 (1937).

same period. The most obvious answer is to displace all the particles simultaneously by the same amount in the same direction. If the displacement z of each particle is small compared with $L/4$, the force F on each particle will be given by $4Tz$. Then the frequency f_{11} of this mode of vibration is given by

$$f_{11}=(16T/\sigma L^2)^{\frac{1}{2}}/2\pi=0.636K.$$

The ratio of this value to that obtained for the fundamental frequency of the uniform membrane is $(2)^{\frac{1}{2}}/\pi$, exactly as in the similar case for the vibrating string.[1]

It is not difficult to see that if particles *1* and *3* are displaced the same amount in the positive Z direction while particles *2* and *4* are displaced a similar amount in the opposite direction, the expression for the force is $8Tz$ and, hence, all particles execute simple harmonic motion of frequency

$$f_{22}=(32T/\sigma L^2)^{\frac{1}{2}}/2\pi=0.896K.$$

Here we have treated this mode of vibration in just the same way that we treated the single mode in Case I. Thus the ratio of the frequency obtained from the model to that obtained for the similar mode in a uniform membrane is $2/\pi$. This error is general for the highest mode of vibration of all our models, as it was in the similar treatment of the vibrating string.[1]

There is still another manner in which all four particles can be made to execute simple harmonic motions of identical period. It corresponds to having any two adjacent particles displaced the same distance in the positive direction while the other two are displaced the same distance in the negative direction. For this mode F is $6Tz$. The frequency, therefore, is[2]

$$f_{12}=(24T/\sigma L^2)^{\frac{1}{2}}/2\pi=0.78K.$$

Case III.—We next consider the membrane to be divided into 9 parts, each of mass $\sigma L/9$ gm. These are assumed to be supported on a net of 6 light strings each stretched by a force of magnitude $LT/3$ dynes. This arrangement is illustrated in Fig. 2.

Since the particles numbered *1*, *3*, *5* and *7* are similarly located, they can be treated alike. This is also true for the particles numbered *2*, *4*, *6* and *8*. Particle *9* is distinguishable from all the others. Now the problem of determining the first mode of vibration for the model amounts to finding simultaneous positive displacements for all the particles so that all vibrate harmonically with the same frequency. Let the displacements of particles *1*, *3*, *5* and *7* be z_1, and those of particles *2*, *4*, *6* and *8* be z_2. Let particle *9* be displaced a distance z_3. Then, for the magnitude of the restoring force on particle *9*, we have[3]

$$F_3=4(LT/3)\{3(z_3-z_2)/L\}=4Tz_3-4Tz_2.$$

The force on each even-numbered particle is

$$F_2=(LT/3)(6z_2/L)+2(LT/3)\{3(z_2-z_1)/L\}-(LT/3)\{3(z_3-z_2)/L\}=5Tz_2-2Tz_1-Tz_3.$$

Finally, the force on any odd-numbered particle, excluding *9*, is

$$F_1=2(LT/3)(6z_1/L)-2(LT/3)\{3(z_2-z_1)/L\}=6Tz_1-2Tz_2.$$

Since, for isochronism $(F_1/z_1)=(F_2/z_2)=(F_3/z_3)$, we have

$$4-4(z_2/z_3)=5-2(z_1/z_2)-(z_3/z_2)=6-(2z_2/z_1).$$

This set of two simultaneous equations is satisfied by taking $(z_3/z_2)=(z_2/z_1)=2$. Thus the frequency f_{11} corresponding to this mode of vibration is given by

$$f_{11}=(3/2\pi L)(2T/\sigma)^{\frac{1}{2}}=0.67K.$$

This result (like the similar representation of the isolated string) is within about 5 percent of the correct value for the uniform membrane.

The second harmonic mode of vibration is obtained by setting the displacements of particle *9* and of the even-numbered particles equal to zero, and the displacements of particles *1* and *5*, represented by z, equal to the negative of the simultaneous displacements of *3* and *7*. The magnitude of the force on any of the displaced particles then is

$$F=2(TL/3)(6z/L)+2(TL/3)(3z/L)=6Tz.$$

[2] Here, since the membrane is divided into two loops in one direction and one loop in the other, we have a hybrid case for which there is obviously no analog in the treatment of a single vibrating string.

[3] Diagrams showing the displacement of the string may be used in connection with the development of these equations. Since the shapes are identical with those shown in reference 1, they are not duplicated here.

The frequency obtained from the formula for simple harmonic motion is

$$f_{22}=(3/2\pi L)(6T/\sigma)^{\frac{1}{2}}=1.17K.$$

The third and highest harmonic mode of vibration for the model is obtained by displacing each particle in the net by the same amount, the sense of the displacement alternating from particle to particle along every string. The law of force is

$$F=4(LT/3)(6z/L)=8Tz,$$

and the frequency is given by

$$f_{33}=(3/\pi L)(2T/\sigma)^{\frac{1}{2}}=1.35K.$$

Another way in which all the particles may be made to execute isochronous simple harmonic vibrations is to displace particles *1*, *2* and *3* in one sense and particles *5*, *6* and *7* in the other. In this mode, because of their similarity, particles *1* and *3* have the same displacement z_1, and particles *5* and *6* are displaced an amount which is the negative of this. We set the displacement of particle *2* equal to z_2 and that of particle *6* equal to $-z_2$. The magnitude of the restoring force on each of the particles *1*, *3*, *5* and *7* is given by

$$F_1=2(TL/3)(6z_1/L)+(TL/3)(3z_1/L)-(TL/3)\{3(z_2-z_1)/L\}=T(6z_1-z_2).$$

The restoring force on particle *2* is

$$F_2=(TL/3)(6z_2/L)+(TL/3)(3z_2/L)-2(TL/3)\{3(z_2-z_1)/L\}=T(5z_2-z_1).$$

Thus the condition for isochronous motion is

$$6-(z_2/z_1)=5-2(z_1/z_2).$$

This equation also is satisfied by setting $(z_2/z_1)=2$, and the resulting frequency is

$$f_{12}=(3/\pi L)(T/\sigma)^{\frac{1}{2}}=0.955K.$$

Yet another harmonic mode of vibration is obtained by letting the displacement of particles *1*, *3*, *5* and *7* be z_1, and the displacement of particles *4* and *8* be $-z_1$. The displacement of particles *2* and *6* is represented by z_2, and that of particle *9* by $-z_2$. The magnitude of the force on each of the particles *1*, *3*, *4*, *5*, *7* and *8* is

$$F_1=3(LT/3)(6z_1/L)-(LT/3)\{3(z_2-z_1)/L\}=T(6z_2-2z_1).$$

The condition for isochronism is

$$7-(z_2/z_1)=6-2(z_1/z_2),$$

and again we find that the condition is satisfied by setting z_2/z_1 equal to 2. The corresponding frequency is given by

$$f_{13}=(3/2\pi L)(5T/\sigma)^{\frac{1}{2}}=1.1K.$$

Finally, we take the displacements of *4*, *8* and *9* to be zero. We let the displacements of particles *1*, *3*, *5* and *7* be z, and those of *2* and *6* be $-z$. The restoring force on any of the displaced particles is

$$F=3(LT/3)(6z/L)+(LT/3)(3z/L)=7Tz.$$

Hence we obtain

$$f_{23}=(3/2\pi L)(7T/\sigma)^{\frac{1}{2}}=1.26K.$$

In these illustrations we notice that the problem of computing the frequency corresponding to an individual mode of vibration for the two-dimensional net is not essentially more difficult than the similar problem for the simple string. The number of modes of vibration, however, increases quite rapidly as the number of strings is increased. Hence it is not desirable to carry the details through for a problem with a much larger number of strings, although we can draw some very interesting conclusions from such considerations.

First, concerning the shapes of the system, we may notice that, in the illustration worked out, the ratio of the displacements z_2/z_1 on the lower string was the same whether the vertical strings were divided into 1, 2 or 3 loops. This ratio of the displacements is also the same as for an isolated string treated in the same manner.[1] Evidently the *shape* of the individual string of a net is entirely independent of the set of strings at right angles and is the same as that for a similar isolated string, provided the conditions are fulfilled for making all parts of the system vibrate isochronously.[4] In the case of the isolated

[4] A critical examination of the foregoing examples shows the reason for this. While, in a given mode of vibration, not all of the restoring force on the particles along the string arises from the string itself, a constant fraction of the total force does. In the limiting case of the uniform membrane this is also true. If the restoring force along the line $x=constant$ is considered, it is found that both the restoring force due to curvature in the Y direction and the restoring force arising from X curvature depend upon y in exactly the same way.

uniform string[1] we saw that, for the parts to execute simple harmonic motion, it was necessary to have the string in sinusoidal form. Since this same condition must be fulfilled by the strings into which the uniform membrane is analyzed, we see that z as a function of x with y held constant will be a sinusoidal function. Similarly z is a sinusoidal function of y if x is held constant. Thus we may conclude that the shape of the membrane as a function of x and y is given by

$$z = A \sin(\pi m x/L) \sin(\pi n y/L), \qquad (1)$$

where m and n represent the number of loops in which the X and the Y dimensions, respectively, of the membrane are divided.

Turning our attention now to the frequencies involved, we should notice first that, in the examples worked out, the "curvature" of the membrane, either in the X or in the Y direction, gave rise to forces which we treated similarly. The two dimensions of our loops can be made to differ sufficiently to make the membrane behave much like a simple set of parallel strings, in contrast with its general behavior as a net. For example, consider the frequency of a mode of vibration such as $f_{100,\,1}$, in which the X dimension is divided into 100 loops and the Y dimension into a single loop. In such a case it works out that the restoring forces arising from the force in the membrane in the Y direction may be neglected in comparison with those arising from the force in the X direction. In this mode of vibration the membrane does act essentially as a set of parallel stretched strings vibrating with similar period and phase. The perpendicular set of strings might be termed "idle" because no appreciable restoring forces arise as a result of the force in them, and the frequency may be computed directly from the formula for the vibrating string. If, however, we consider the calculation of the frequency of the mode in which both the X and Y dimensions of the membrane are divided into 100 loops, we can see at once that $f_{100,\,100}$ will approximately equal $(2)^{\frac{1}{2}} f_{100,\,1}$, because, in this second case, we have two forces acting on each vibrating segment and each is as large as the dominating force in the preceding case.

The similarities between the membrane and the string have been indicated. The displacement as a function either of x or of y is identical with that of a string having a similar number of mass points and loops. When the X dimension of our model is identical with the Y dimension in mass distribution and number of loops, the precision of the representation as compared with the correct value for the uniform membrane is numerically the same as for the similar representation of the vibrating string. However, because in the stretched membrane the stretching forces act both in the X and in the Y direction, there are also a number of dissimilarities. The frequencies in general cannot be computed from the formula for the vibrating string. The allowed frequencies are much more numerous than they are for the vibrating string. We have the fundamental, f_{11}, and a set of overtones, f_{22}, f_{33}, etc., which are harmonics and correspond to the harmonics of a vibrating string. In general, however, the overtones are not harmonics, and the poor musical quality of the sound from a stretched membrane is a consequence of this fact.

General Treatment of a Rectangular Membrane

We could, of course, treat the rectangular membrane with unequal sides by division into mass points in a manner that is entirely analogous to that used for the square. It is at once evident that additional, distinct frequencies may be introduced because of the inequality of the sides.[5] Dividing the length of the membrane into two loops and the width into one loop will give a frequency differing from that obtained by dividing the length into one loop and the width into two. Thus, because of the increased number of frequencies involved and because the methods appear to have been illustrated in sufficient detail, it appears preferable for the case of the rectangular membrane to deduce what general results we can from a knowledge of the forces and masses involved.

Consider a rectangular membrane with its length a divided into m loops and width b divided into n loops. We ask how the numbers a, b, m and n influence the frequency of vibration. For this purpose it will be sufficient to imagine the mass of the membrane divided into mn mass points located at the intersections that m strings in the one direction make with n strings in the other (Fig. 3). Here we have m strings, each stretched by a force of magnitude aT/m, lying parallel to the side b, and n strings stretched by a force of magnitude bT/n, lying parallel to the side a. The force on each particle when the highest mode of vibration is excited can be expressed in the usual way by the formula

$$F = 2(aT/m)(2zn/b) + 2(bT/n)(2zm/a) = 4T\{(an/bm) + (bm/an)\}z.$$

Hence the frequency of vibration obtained from this representation is

$$f_{mn} = (1/2\pi)\{4T(an/bm + mb/an)zmn/zab\sigma\}^{\frac{1}{2}} = (1/\pi)\{(T/\sigma)[(n/b)^2 + (m/a)^2]\}^{\frac{1}{2}}. \qquad (1)$$

[5] This is often expressed by saying that the square membrane is "degenerate" and that making the two dimensions unequal removes the degeneracy.

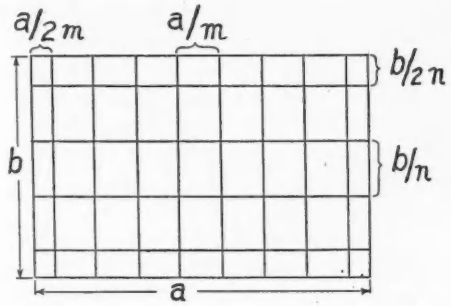


FIG. 3.

Here we have considered the mass in each loop to be concentrated at a single point in the center. We have learned that to obtain the correct frequency for a uniform mass distribution, we must multiply this frequency by $\pi/2$. Thus we conclude that the frequencies for the uniform membrane will be given by

$$f_{mn}=(1/2)\{(T/\sigma)[(n/b)^2+(m/a)^2]\}^{\frac{1}{2}}. \quad (2)$$

In the argument leading to Eq. (1) we saw that for the harmonic modes of vibration, the shape of the loops along individual strings approached a sinusoidal form as the distribution of the mass was made more uniform. Since this conclusion does not depend upon loops being of the same length in the two directions, it is apparent that Eq. (1) could be altered to cover the case of the rectangular membrane simply by writing it in the form

$$z=A \sin (\pi mx/a) \sin (\pi ny/b). \quad (3)$$

An equation of this form is capable of giving the displacement, at any particular time, of any rectangular membrane vibrating in any of its simple harmonic modes. Let us choose A to give the Z coordinates at a time when the displacement of each particle is a maximum. Then, since the displacement of each particle in the membrane as a function of the time varies sinusoidally with frequency f_{mn}, we may write

$$z=A \sin (\pi mx/a) \sin (\pi ny/b) \cos (2\pi f_{mn}t). \quad (4)$$

This equation, together with Eq. (2) for determining the allowed frequencies, contains the essential predictions as to the behavior of a uniform membrane when its various parts are vibrating in simple harmonic motion. Any actual motion of the diaphragm consists of some combination of such modes.

The analysis of the uniform membrane into two sets of strings at right angles seems quite reasonable since it can be made to represent the mass distribution and the system of forces correctly. The emphasis placed upon simple harmonic motion provides a proper background for further studies in vibration. The simplicity of this particular two-dimensional case permits its use in classes of very limited mathematical training. The directness with which the physical principles are applied has very obvious advantages which make it useful as an introductory study even where mathematical restrictions are not troublesome.

Through a similar treatment of the membrane bounded by a rigid circle, one can obtain an approximate solution for the problem of the vibrating drumhead. The results obtained in this case suggest the properties of Bessel functions before one has proceeded very far, and the method provides a physical introduction to the meaning of such functions. In this connection it should also be mentioned that the present method of treating a problem yields approximate information concerning membranes when they are bounded in such a way that the exact solutions cannot be obtained.

Portraits of Eminent Physicists

ONLY a few more preliminary subscriptions are needed to insure publication of *Portraits of Eminent Physicists*, a portfolio of portraits of twelve eminent physicists, with biographical sketches written by Professor Henry Crew. The prepublication price is $2.00, payable on delivery. Any subscriber who finds the portfolio unsuitable may return it at the expense of the publisher. Orders should be sent immediately to *Scripta Mathematica*, Yeshiva College, New York, N. Y.

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Reproductions of Prints, Drawings and Paintings of Interest in the History of Physics

7. A Meeting of the Académie Royale des Sciences in the King's Library in Paris on the Occasion of a Visit by Louis XIV in 1671.

E. C. Watson
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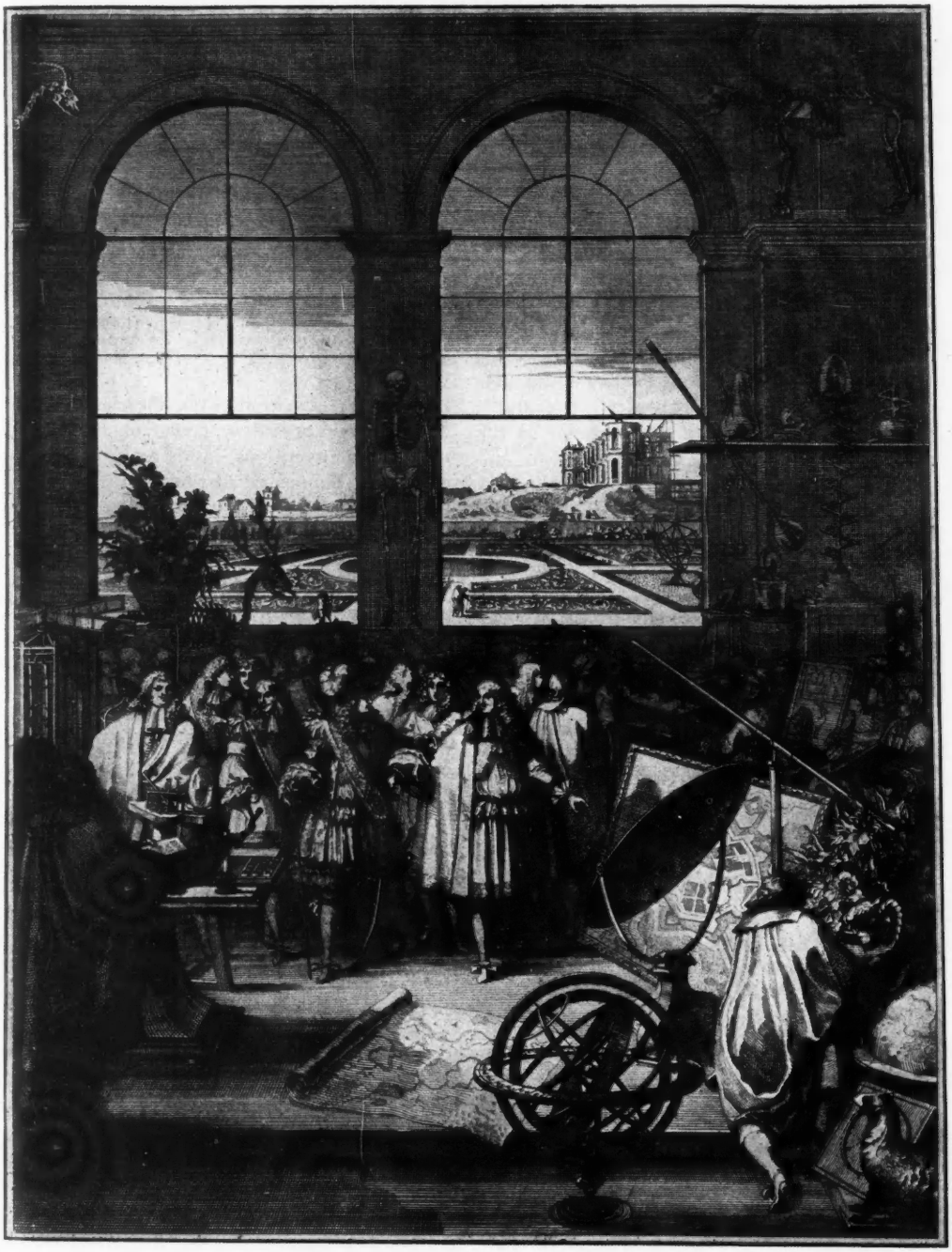
THE Académie Royale des Sciences had its origin[1] in certain informal gatherings of scientists and mathematicians in Paris during the first half of the seventeenth century. Marin Mersenne (1588–1648), Pierre de Fermat (1601–1665), René Descartes (1596–1650), Gilles Personne de Roberval (1602–1675), Pierre Gassendi (1592–1655), Blaise Pascal (1623–1662), Christiaan Huygens (1629–1695) and others met, irregularly at first, in Mersenne's cell (he was a Minorite Friar), then more regularly at various houses, then regularly at the houses of Habert de Montmor (d. 1679) and Melchisedec Thevenot (1620–1692). Finally Louis XIV's minister, Jean Baptiste Colbert (1619–1683), proposed to the King the establishment of a formal Academy under royal patronage. Two small rooms were set aside for their meetings in the King's Library, a rather drab building on the Rue Vivienne in Paris, near the present location of the Bibliothèque Nationale (not at Versailles as has been often stated). The first formal meeting was held on December 22, 1666. Members received pensions from the King and financial assistance with their researches. At first the members worked together in the laboratory, which constituted one of the rooms in the King's Library, and in the adjoining garden; the early publications of their work were for the most part joint publications. Additional facilities for experimental work in astronomy and physics were soon provided by the erection of the Paris Observatory. During the lifetime of Colbert the Academy flourished. A summary of its work will not be attempted here; such summaries will be found in M. Ornstein's *The Rôle of the Scientific Societies in the Seventeenth Century* and in the references there cited. After Colbert's death in 1683, the work of the Academy "was diverted from pure science to the practical details of constructing the new paradise at Versailles" and "to serving the personal curiosities of the King and State." A complete reorganization and revival took place in 1699 and the Academy moved to quarters in the Louvre which it occupied until its dissolution in 1793.

The print here reproduced is probably the earliest pictorial representation of an actual meeting of a scientific society that we have. It is from a beautiful engraving, 12×16 in. in size, executed by Sébastien Le Clerc in 1671 and used as a frontispiece to at least four of the sumptuously printed very large folio volumes of the early work of the Academy, many of which were distributed as personal gifts by Louis XIV. These volumes were the *Memoires pour servir a l'histoire naturelle des Animaux* (Paris, Imprimerie Royale, 1671–76), the *Recueïl de plusieurs traitez de mathematique* (Paris, Imprimerie Royale, 1676–77), the *Memoires pour servir a l'histoire des Plantes* (Paris, Imprimerie Royale, 1676) and the *Estampes pour servir a l'histoire des Plantes* (1701). Of these the *Recueïl de plusieurs traitez de mathematique* is of the most interest to physicists. It includes Mariotte's *Traité de la percussion ou choq des corps* (1676), *Lettres ecrites par MM. Mariotte, Pecquet et Perrault, sur le sujet d'une nouvelle découverte touchant la veuë faite par M. Mariotte* (1676), Mariotte's *Traité du nivellement* (1677) and Frenicle's *Traité des triangles rectangles en nombres* (1677). My own copy has bound with it also Picard's *Mesure de la Terre* (Paris, Imprimerie Royale, 1671) and Blondel's *Resolution des quatre principaux Problemes d'architecture* (1673). The size of the volume and the beauty and quality of its binding, paper and printing, together with the engraved frontispiece, vignettes, *lettres grises*, plates, and tailpieces make this probably the most magnificent work on physical science ever printed.

[1] See A. J. George, "The Genesis of the Académie des Sciences," Ann. Sci. 3, 372 (1938).



A meeting of the Académie Royale des Sciences in the King's Library in Paris.

SÉBASTIEN LE CLERC (1637–1714) was the most prolific engraver of the seventeenth century as well as one of the best. As engraver to LOUIS XIV he illustrated most of the early publications of the Académie des Sciences and his engravings constitute a contemporary pictorial record of the Academy's personnel, apparatus, meetings and proceedings from 1670 to 1714 that is not only unique but also remarkable in its amount and its accuracy. Trained and practiced as an engineer as well as an engraver, a lifelong student of physics, geometry and perspective, a minutely painstaking and precise draughtsman, he was able to depict the work of the Academy and its various scientific instruments with the greatest fidelity and understanding. His work affords an excellent example of the effective use of scientific material by the artist, as well as of the values of art in describing, recording and humanizing scientific achievements.[2]

Many of the figures in this engraving are clearly portraits. Thus the two central ones are LOUIS XIV and COLBERT. To their right are LOUIS DE BOURBON, PRINCE DE CONDÉ (1621–1686) and the King's brother, PHILIP, DUKE OF ORLEANS (1640–1701). CLAUDE PERRAULT (1613–1688), architect, physician, inventor, anatomist, naturalist and the most active member of the Academy, stands just behind COLBERT and the King; and the figure, between the PRINCE DE CONDÉ and the King's brother, who is talking so enthusiastically over his shoulder and pointing to some of the exhibits is GIOVANNI DOMENICO CASSINI (1625–1712), the astronomer who was called from Italy to become the head astronomer of the Academy and who, with his family, made the Paris Observatory the foremost in the world. JEAN PICARD (1620–1682), one of the best astronomers of the seventeenth century and one of the most active members of the Academy, is shown at the extreme right of the print holding in his hands one of the large folio volumes of his *Mesure de la Terre*, which was just off the press. It should be possible to identify several of the other figures, especially the man to whom CASSINI is talking, the two figures describing to the visitors the large model of what may be the water works at Versailles (right background of the print), and the figure beside PICARD. The writer can only guess, however, that the last is PIERRE DE CARCAVI (d. 1684), mathematician and custodian of the Library where the meetings were held, and that the two figures beside the model are FRANÇOIS BLONDEL (1617–1686) (left) and CLAUDE-ANTOINE COUPLET (1642–1722) (right).

From the beginning the Academy made a collection of apparatus—tools, machines, instruments and inventions—and many of them are accurately delineated in this engraving. Thus a telescope and one of VILLETE's burning mirrors appear in the foreground, and the vacuum pump constructed by HUYGENS in 1668 stands at the left beside the table on which rests a compound microscope (probably one of those constructed by HUYGENS). In the background are models of various machines and several pieces of chemical apparatus. The number and size of the stills show clearly the prominent rôle that distillation played in the experiments of the Academy, while the Academy's interest in map making and fortifications is indicated by the rolled map and large chart in the foreground.

That the astronomers of the Academy at first worked in the garden adjoining their meeting place is cleverly suggested by the large quadrant which may be seen through the Library windows. Moreover, the building shown under construction in the distance is clearly the Paris Observatory which was actually nearing completion at the time LE CLERC was engraving the plate. It is true that the Observatory was erected on the Faubourg St. Jacques more than two miles south of the King's Library and across the Seine; but, because of the vital part that the Observatory played in the work of the Academy, we may well forgive the artist for shortening the distance.

[2] For further information regarding Le Clerc's life and the scientific aspects of his work see "The Early Days of the Académie des Sciences as Portrayed in the Engravings of Sébastien Le Clerc," Osiris, in print, from which these notes were taken almost verbatim.

Science has grown out of practical lore and it has nothing to gain, but much to lose, by forgetting its origin.—J. ARTHUR THOMSON, *Introduction to Science* (1911).

On the Meaning of a Constant in a Physical Law—a Discussion by the Three Characters of Galileo's Two New Sciences

Transcribed by H. M. DADOURIAN
Department of Mathematics, Trinity College, Hartford, Connecticut

SIMPLICIO. As a topic of discussion for today I should like to offer the question of re-forming the equations of mathematics and the laws of physics along the lines laid down by certain authors of elementary physics textbooks, who write the force equation as $F=kma$. By introducing k into this equation, these authors have given recognition to the fact that F is jointly proportional to m and a. Why not carry this plan to its logical conclusion? Why not write, for example, $A=kxy$ for the equation giving the relationship between the area of a rectangle and the lengths of its sides?

SAGREDO. I suppose the value of k will change with the system of units used. Wouldn't that be rather inconvenient?

SIMP. Putting the equations of mathematics and physics on a sound theoretical basis comes first. When that is done, the inconvenience can be eliminated by following the practice of some elementary physics books which use the poundal and the slug to make k unity. I propose that we adopt two new units of length to be called the *footal* and the *flug*, defined as follows:

The footal is that unit of length which will make k unity when the British units of acres and feet are used. One footal equals $43560^{\frac{1}{2}}$ feet.

The flug is that unit of length which will make k unity when the English system of units of acres, rods and feet is used. One flug equals 264 feet.

SALVIATI. You are saying in effect, "Since the value of a quantity may be obtained in one unit and desired in another, every equation of physics should contain a conversion constant and new units should be devised to make the constant unity."

SIMP. That is exactly what I mean.

SALV. Under your scheme we should have $V=kxyz$, $v=ks/t$, $a=kv/t$, and so on. Even the length of a rod should be expressed as $l=kl_0$, where l_0 is the length in terms of the unit used in measuring it and l the length in terms of the desired unit. Simplicio, have you thought about the consequences of carrying such a scheme to its logical conclusion? As an example, let us see what will happen to the expression for the work done in giving a body a velocity. We shall have $W=k\int F\cos\theta ds$, where $F=k_1mdv/dt$, $m=k_2m_0$, $v=k_3ds/dt$, $s=k_4s_0$, $t=k_5t_0$; $\theta=k_6\theta_0$. The result of the integration—the expression for the kinetic energy—will contain these seven k's, but will be written in the form $E=\frac{1}{2}kmv^2$. We shall have also equations connecting the various constants. Thus, textbooks of mathematics and physics will become cluttered with k's.

SAGR. Yes, Simplicio would make mathematics and physics, which are the sciences of variables, the sciences of many k's, the very "Kink" and the "Queenk" of sciences. Simplicio, your footal is "footless" and your flug is "flooey;" as to your k's, they are simply "cuckoo."

SIMP. Don't be flippant. So far as I see, my theoretical reasons for introducing k have not been challenged.

SALV. Your "theoretical reasons" are based upon a misconception. By saying that A varies jointly with x and y, you tacitly assume that area is defined or measured independently of length—a false assumption. The area of a rectangle is, by definition, the product of its dimensions. I am afraid, Simplicio, you have no case.

SAGR. There is something that worries me. Though I can see the foolishness of our friend's plan, I do not see that there is anything wrong about the pattern on which he has shaped it. You do not object, I am sure, to the presence of k in the force equation, $F=kma$, and in Hooke's expression for the elongation of a spring, $F=kl$.

SALV. Let us consider $F=kl$ first. Hooke measured the force and the corresponding elongation, and found that they are proportional. In other words, he found that there exists a relationship of proportionality between two physical magnitudes which are independently defined and measured. Therefore it is perfectly proper to write $F=kl$. Here k is a constant of proportionality that represents a physical property of the subject of the experiment, and has dimensional qualities. As I pointed out before, A is not defined or measured independently of length. In fact, xy is, by definition, the area of a rectangle. It is the area, whatever the units in which x and y are measured. When we write $A=kxy$, we are introducing a purely numerical constant that has nothing to do with the area itself.

SIMP. Yes, but why should we reject conversion constants when we accept proportionality constants?

SALV. I have indicated what will happen to equations of mathematics and physics when we begin to introduce into them conversion constants. Besides, conversion constants serve no useful purpose. When we write $A=xy$, we do not commit ourselves to any system of units. Because the length and the width of a rectangular farm, for example, may be measured in feet and its area required in acres, it is not necessary to write $A=kxy$. If you measure the sides in feet, you obtain the area in square feet; then, if you want it in acres, all you have to do is to divide the result by 43560. If you find this difficult, any grammar school child will be glad to help you.

SAGR. I gather then that you have no objection to $F=kma$.

SALV. As a matter of fact, there is less justification for the presence of the notorious k in the force equation than in the area equation, and less is to be said for the poundal and slug than for the footal and flug.

SIMP. You don't mean to imply that force is not proportional to mass as well as to acceleration?

SALV. I certainly do. When you say that F is proportional to m and a, you assume that these three quantities are defined or measured independently—another false

assumption. Only two of these are measured or defined independently. We may look at the force equation either as the definition of force or as the definition of mass. If we start with time, length and mass as the fundamental magnitudes of mechanics, we have to accept the first view, in which case k becomes a conversion constant, not a constant of proportionality. In that case there is as little to be said for $F=kma$ as for $A=kxy$. If we start with time, length and force as the fundamental magnitudes, and, following Galileo's example, investigate the relationship between F and a, we find that F is proportional to a; that is, $F=ka$. In this equation k, the constant of proportionality, represents a physical property of the body used in the experiment; it is called the *mass* of the body and is denoted by m, hence the equation $F=ma$. Those who write $F=kma$ are using, unwittingly, two constants of proportionality where one is ample.

SAGR. Suppose we change the experiment and give the same acceleration to different bodies, then F is proportional to m; that would make a the constant of proportionality. There must be something fishy in your argument.

SALV. Your difficulty arises from two misconceptions. One of them is due to confusing continuous variation with discontinuous change. When a continuously varying force acts upon a body, the acceleration changes continuously and linearly with the force; therefore it is perfectly proper to say that *the* force varies with *the* acceleration. When, however, several bodies are given equal accelerations, not only different masses but also different forces are involved; therefore it is not proper to speak of *the* force being proportional to *the* mass. The second misconception. . . .

SIMP. Before you go further, I want to remind you of the relativity change of mass. It seems to me that your last argument fails in that case.

SALV. What fails in that case, is the force equation of elementary physics. Neither $F=kma$ nor $F=ma$ is valid when m is subject to relativity change. The equation $F=(d/dt)(mv)$ holds, however, whether m is variable or constant. This equation reduces, of course, to $F=ma$ when m is constant. This question of the relativity change of mass is not pertinent to our discussion, however, because we are concerned only with the force equation of elementary physics in which m is taken to be constant.

SAGR. Let's have the second misconception you started to mention.

SALV. That relates to the nature and meaning of a constant of proportionality in a physical law, or equation. Such a constant always stands for a characteristic property of a body, or of a substance, or of a medium; it is never a pure number. For example, in $E=RI$, R is the electric resistance of a wire carrying a current; in $s=\lambda x$, λ is the modulus of elasticity of the substance of an elastic body under strain; in the law of gravitational attraction, G is a property of the gravitational field or space. I can go on indefinitely giving examples in which the constant of proportionality represents some physical property with dimensional qualities. In $F=kma$, k is not only superfluous but, being a pure number, is at variance with constants in other physical laws.

SAGR. Aren't you forgetting the fact that k and μ in Coulomb's laws are sometimes treated as pure numbers; that is, as conversion constants?

SALV. The question of the nature of the constants in the equations of electricity and magnetism is complicated by the fact that electric charges and magnetic masses, magnitudes which are not found in mechanics, enter into these subjects. There is a divergence of opinion among physicists on the question of the number of fundamental magnitudes to be adopted in electricity and magnetism. The interminable controversy over the electrical units is due to this. For that reason, we shall do well to confine our discussion to mechanics, where there is a complete agreement about the number of the fundamental magnitudes.

SIMP. I grant that your objections against conversion constants are well taken, so far as simplicity of equations and consistency of notation are concerned; but I maintain that there is something to be said for k in $F=kma$, for the poundal and for the slug on practical and pedagogic grounds. These enable students to solve problems that involve weight; I tell you, it works.

SALV. There can be no practical use for them; otherwise they would be used in engineering and advanced physics. Who has ever heard weight spoken of as so many poundals or so many slug-feet-per-second-per-second, outside of a classroom in elementary physics? Even in such classrooms these gewgaws are not mentioned after the first chapter or two. As for the pedagogic argument that "it works," it works simply because problems are so phrased that "it" can't help working. It works in the sense that your footal would work in the problem, "What is the area of a rectangular farm that is 3 footals long and 2 footals wide?" All that the student has to do is multiply 3 by 2 to obtain the answer.

SAGR. I am not for pedagogic trappings which are intended to enable students to find the answers to foolishly phrased questions. Furthermore, I can see that the "notorious k," the poundal and the slug serve no useful purpose in theory or in literal problems. But numerical problems present both the teacher and the student with a difficult situation.

SALV. Don't you think the difficulty of that situation is mainly due to the multiplicity of units?

SAGR. I do. If we used only the cgs system of units, there would be less confusion.

SALV. Then you cannot reasonably maintain that increasing the number of units will reduce the confusion.

SIMP. It is not within our power to do away with the British system of units or the gravitational units in the metric system.

SALV. True; but we can do a number of things. First, we can refrain from using the poundal and the slug, thereby reducing the number of units by two. Second, we can refrain from introducing a superfluous k, whose value jumps back and forth with 1/980, 1/32 and 1 as stepping stones; this gives the student the jitters. Third, we can stop talking about the "pound-force" or the "force-pound," and the "pound-mass" or the "mass-pound." These are nonsensical terms which perplex the intelligent student. If the pound is a unit of force, what are "pound-

force" and "pound-mass?" Why call a force "force-force," and a mass "force-mass?"

SAGR. You have told us how not to aggravate the confusion of the student, but you have not shown us how to reduce the confusion that will exist even if we refrain from doing the things you have warned us against. How is the student to solve, for instance, a numerical problem in which weight is given, and force or momentum or energy is required?

SALV. Let me show you a way which is not only theoretically sound but also very simple. Train the student to follow these rules: (1) *Using letters, find an expression for the required quantity.* (2) *Perform the necessary literal substitutions until every letter in the expression represents a given or a known quantity.* (3) *Put the given numerical values in the expression after the second rule is complied with, never before.* These are invaluable rules; they save time, reduce the number of numerical blunders and are aids to clear thinking. As an illustration of the simplicity of this method, suppose w and a are given, and F is required. The student writes $F=ma$; then, since m is not given, he looks for an equation by means of which he can eliminate it; he thinks of $w=mg$ and, making use of it, obtains $F=wa/g$. The rest is a matter of mere substitution of numerical values. As simple as that.

SIMP. Then you favor writing w/g for mass, and $F/w=a/g$ or $F=wa/g$ for the force equation.

SALV. Not at all. In fact, I object to these more than to $F=kma$, for the following reasons. The equation $F/w=a/g$ reduces a physical law, a very important one at that, to a mere numerical equation; for both F/w and a/g are pure numbers. On the other hand, $F=(w/g)a$ suffers from the disease of circularity, when considered as the definition of force. You will admit that a definition which expresses a force F in terms of another force w is not a legitimate definition. As to the use of w/g as the general definition of mass, there is little to be said for it. Authors who represent mass by w/g in the equations of physics ignore the fact that mass, being the most important property of matter, deserves a symbol of its own; they confuse a physical quantity with a particular way in which it may be measured under certain limited circumstances; they revert to geocentricism without being aware of it.

SIMP. I do not see the connection between that definition of mass and geocentricism.

SALV. We all agree that mass is a property of all bodies, small or large, terrestrial or celestial. Let us see what happens to that definition of mass when applied to the sun. According to that definition, *the mass of the sun equals the weight it would have if it were on the surface of the earth, divided by g.* But this statement is sheer nonsense. What possible meaning can we attach to the phrase, "the sun on the surface of the earth," or to "the weight of the sun when it is on the surface of the earth?" If the sun and the earth were in contact, there would be some sense in saying that the earth is on the surface of the sun, but not in putting it the other way around. If we consider the weight of the sun to be the gravitational attraction between the two bodies when they are in contact, w/g will not give the sun's mass. This definition of mass gives an approximate value of the mass of a body when its mass and dimensions are small compared with the mass and the radius of the earth. But when either the mass of the dimensions of the body are large, the definition loses all meaning. Why then use such a definition and make use of it in equations that are supposed to be applicable to all bodies?

SIMP. It seems to me that you used that definition of mass a few minutes ago, by making use of $w=mg$ to eliminate m in $F=ma$.

SALV. I am afraid I produced a wrong impression by making my statement too brief. I should have said, "Since the mass and the dimensions of the body are small compared with those of the earth, we may let $F=w$ and $a=g$, and obtain $w=mg$." You must admit that this statement is not the same as using $m=w/g$ for the general definition of mass.

SAGR. I see clearly what you are driving at. The shortcomings of that definition of mass will become even more evident when we apply it to the earth. Because, the definition says, "The mass of the earth equals its weight when it is on its own surface, divided by g." Evidently it is nonsense to talk about the earth being on its own surface.

SALV. After this striking remark of Sagredo's, further discussion will result in an anticlimax. Friends, let us call it a day.

SIMP. Before adjourning, Salviati, would you mind restating briefly the more important points you have made?

SALV. With pleasure. Here they are.

First. The poundal and the slug are units we can dispense with to advantage; especially, if we follow the rules I have suggested for solving numerical problems.

Second. We must distinguish between constants of proportionality and constants of conversion. A constant of proportionality stands for a physical property without which most equations of physics would be nonhomogeneous. A conversion constant is a purely numerical coefficient which has no legitimate place in the fundamental equations of mechanics.

Third. Since mass is a property of all bodies, avoid defining it in such a way that the definition becomes meaningless when applied to bodies whose masses and dimensions are not negligible compared with those of the earth.

Fourth. If we grant the last two points, we shall have to admit that the proper form of the force equation is $F=ma$ or $F=d(mv)/dt$; it is not $F=kma$ or $F=(kw/g)a$ or $F=(w/g)a$ or $F/w=ka/g$ or $F/w=a/g$.

The Postprandial Proceedings of the Cavendish Society. II*

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A Function of the Time.—Sir Oliver Lodge was invited to the 1907 dinner, and Robb composed this song in his honor. "Bradshaw" is *Bradshaw's Railway and Steamboat Guide*, the timetable with which everyone who traveled in England in those days was familiar. "The Derby" is, of course, the great horse race run at Epsom Downs near London.

A FUNCTION OF THE TIME

Air: "Society has quite forsaken" (*Utopia Limited*).

1 Dame Nature she is quite forsaking all mysterious courses,
And soon all things will be expressed in terms of well-known forces,
Of forces with a definite potential.
No tolerance will then be shown to any sort of mystery,
As soon as we can calculate all past and future history,
For Haeckel says this is most essential.
Then should perchance some spook attempt to rock the breakfast table,
Sir Oliver, you may be sure, will catch it if he's able.
And first he will investigate all spooks and their relations,
Then give them n coordinates and use Lagrange equations.

Chorus It really is surprising what a thorough organizing
Can do in raising science to a higher sphere.
By our enterprising movements
We are making such improvements
That we'll soon be quite familiar with "the not quite clear."

2 When science once has reached this stage it really will be splendid,
All philosophic doubts will then be definitely ended,
And men will know exactly what they're doing.
Each individual corpuscle will then have been detected,
We'll look up in a Bradshaw and we'll find when one's expected,
And follow out the course it is pursuing.
Of every role the æther plays we'll have a clear conception,
Of waves of thought, and also their transmission and reception.
The Psychical Society will drive out superstitions
And only deal with ∇^2's and boundary conditions.

3 The atoms at a given time will all reach certain places,
They'll calculate the Derby out instead of running races,
And gambling then must needs go out of fashion.
And then, unless in science you are but a mere beginner,
You'll reckon out the very words your friend will say at dinner,
And this is sure to put him in a passion.
But what becomes of passions be they anger, joy, or sorrow,
If we can know and think today the thoughts we'll think tomorrow?
Thus *time* itself becomes obscure; this is a serious question,
Don't think of it at dinner time, 'twill give you indigestion.

An Aethereal Swain.—This was sung in honor of the second guest of the 1907 dinner, Professor Joseph Larmor the mathematician, who is still living but retired. It is interesting to note that the earlier theories declared that a revolving electron was radiating, whereas, on Bohr's newer theories, radiation occurs only when the electron jumps from one orbit to another. In such a way do theories change as the years roll on—and many students take theories for facts.

AN AETHEREAL SWAIN

Air: "Egypt."

1 Within the College of St. John there dwells a famous man,
Whose name is most familiar, I'll describe him if I can.
His fame has widely spread abroad to every distant shore,
Where physicists do all revere Professor J. Larmor.

Chorus He is dreaming of electrons, æther and matter—
Dreams that would shatter
Our feeble brains.
He is dealing with "least actions,"
And vague abstractions,
And "freely mobile intrinsic strains."

2 In moving systems he explains the nature of a ray.
The aberration of the stars he makes as clear as day.
From Michelson and Morley's work he readily can prove
Material bodies change in size whenever they do move.

* Part I appeared in the June issue, p. 179.

3 He clearly shows that when a charge accelerates
its pace,
A stream of radiation flows away through boundless space;
The rate of loss of energy he boldly hath declared
Is in direct proportion to acceleraton squared.

An Alpha-Ray.—Professor Rutherford was awarded the Nobel prize for chemistry in 1908. His success on elucidating the properties of the α-particles is celebrated in this popular song by Robb, rendered for the first time at the 1908 dinner with Rutherford as our second guest. Here we see the speed, charge, ionizing power, scintillation production and final state of the α-particle all melodiously brought into a lively rhyme.

AN ALPHA-RAY

Air: "A Jovial Monk."

1 An alpha-ray was I, contented with my lot;
From radium C
I was set free,
And outwards I was shot.
My speed I quickly reckoned,
As I flew off through space,
Ten thousand miles per second
Is not a trifling pace!
For an alpha-ray
Goes a good long way
In a short time t,
As you easily see;
Though I don't know why
My speed's so high,
Or why I bear a charge $2e$.

2 And in my wild career, as swiftly on I flew,
A rarefied gas
Wouldn't let me pass,
But I pushed my way right through.
I had some lively tussles
To make it ionize,
But I set the small corpuscles
A-buzzing round like flies.
For an alpha-ray
Hasn't time to stay
While a trifling mass
Of expanded gas,
That stands in awe
Of Maxwell's law,
Obstructs the road when I want to pass.

3 An electroscope looked on, as I made that gas conduct;
Beneath the field
The gas did yield
And the leaf was greatly "bucked."
But in my exultation
I lost my senses clean,
And I made a scintillation
As I struck a zinc blende screen.
For an alpha-ray
Makes a weird display
With fluorescence green
On a zinc blende screen,
When the room's quite dark,
You see a spark
That marks the spot where I have been.

4 But now I'm settled down, and move about quite slow;
For I, alas,
Am helium gas
Since I got that dreadful blow.
But though I'm feeling sickly,
Still no one now denies,
That I ran that race so quickly,
I've won a Nobel prize.
For an alpha-ray
Is a thing to pay,
And a Nobel prize
One can not despise,
And Rutherford
Has greatly scored,
As all the world now recognize.

"$h\nu$."—Times change. The quantum comes on the scene and the laws of radiation are clarified by Planck and his successors. The wave theory, however, still holds the field in its beautiful explanation of interference of light and diffraction effects. The two rival theories seem inconsistent yet both are necessary; as Sir William Bragg said "We teach the wave theory on Mondays, Wednesdays and Fridays and the quantum theory on Tuesdays, Thursdays and Saturdays." The author of this song is G. Stead, a Cambridge graduate, teacher and author of a well-known textbook on general physics.

"$h\nu$"

Tune: "Men of Harlech."

1 All black body radiations,
All the spectrum variations,
All atomic oscillations
Vary as "$h\nu$."

Chorus Here's the right relation
Governs radiation,
Here's the new,
And only true,
Electrodynamical equation;
Never mind your d/dt^2,
Ve or half mv^2
(If you watch the factor "c^2")
"ψ" equal to "$h\nu$."

2 Ultraviolet vibrations,
X- and gamma-ray pulsations,
Ordinary light sensations
All obey "$h\nu$."

3 Even in matters calorific,
Such things as the heat specific
Yield to treatment scientific
If you use "*hν*."
4 In all questions energetic
Whether static or kinetic,
Or electric, or magnetic,
You must use "*hν*."
5 There would be a mighty clearance,
We should all be Planck's adherents
Were it not that interference
Still defies "*hν*."

Induced Activity.—J. J. Thomson retired from the active directorship of the Cavendish Laboratory in 1919 and E. Rutherford left the University of Manchester to take his place. Apparently Rutherford found the Cavendish Laboratory in a rather untidy state, so his first job was to get it cleaned up and the walls whitened. The remains of Rayleigh's and Maxwell's apparatus were moved to the museum. More instruments were obtained for everyday use and the inevitable typewriter installed. Old-timers hardly recognized the place in its new setting. Robb celebrates the housecleaning in this lively ditty. The title as a suggestion of the relation between Thomson and Rutherford, and also of the activity of Rutherford in his new home, is an exceedingly pretty play of words.

Lincoln (usually called Fred) was the chief workman. His moustache was a thing to wonder at. He had charge of the stores, and many an old researcher had to get on his right side in order to obtain as much as a cork. In his spare time he sailed a dinghy on the Cam, the moustache being very useful for telling which way the wind blew.

INDUCED ACTIVITY

Air: "I Love a Lassie."

1 We've a professor,
A jolly smart professor,
Who's director of the lab in Free School Lane.
He's quite an acquisition
To the cause of erudition,
As I hope very briefly to explain.
When first he did arrive here
He made everything alive here,
For, said he, "The place will never do at all;
I'll make it nice and tidy,
And I'll hire a Cambridge *lidy*
Just to sweep down the cobwebs from the wall."

Chorus He's the successor
Of his great predecessor,
And their wondrous deeds can never be ignored:
Since they're birds of a feather,
We link them both together,
J. J. and Rutherford.
2 Said he, "I wonder
How, in the name of thunder,
All this rubbish has accumulated here.
Since Maxwell and since Rayleigh
It has been a-gathering daily,
That's a thing that is manifest and clear."
And so he spoke to Lincoln,
And, said he, "I have been thinkin'
That the lab is not as neat as it might be;
You understand my meaning,
That it needs a darned good cleaning,
As I think, Mr. Lincoln, you'll agree,"
Chorus He's the successor, etc.
3 Such is the story
Of how the laboratory
Came to look again so tidy and so bright;
The Prof was so elated
When he saw it renovated
He at once started whistling with delight.
So great was the temptation
To begin investigation
That he started his researches there and then,
And what he's been achieving
Would be almost past believing
If he weren't quite a marvel among men.
Chorus He's the successor, etc.
4 What's in an atom,
The innermost substratum?
That's the problem he is working at today.
He lately did discover
How to shoot them down like plover,
And the poor little things can't get away.
He uses as munitions
On his hunting expeditions
Alpha-particles which out of radium spring.
It's really most surprising,
And it needed some devising
How to shoot down an atom on the wing.
Chorus He's the successor, etc.

Isotopes.—F. W. Aston came to the Laboratory in about 1910 as J. J. Thomson's assistant, succeeding G. W. C. Kaye who had left for the National Physical Laboratory. Aston was a great glass blower and quickly made himself known. Associated at first with G. P. Thomson (J. J.'s son), he designed the mass spectroscope, whence has arisen the work on isotopes so closely connected with his name. He was awarded the Nobel prize in chemistry in 1922 and, at the next

dinner, was celebrated in this song written by E. C. Stoner to the well-known Gilbert and Sullivan tune in "The Gondoliers." The last time I saw Aston in the Cavendish he was soldering up the connections of about a thousand little 2-v accumulators, not trusting this work to anyone else. In his spare time he takes to music and the mountains.

ISOTOPES

Tune: "The Highly Respectable Gondolier" (*The Gondoliers*).

1 Since J. J. on the game began
By analyzing neon,
Many a speculative man
Had isotopic thoughts which ran
Beyond a paper's rightful span,
So this did all agree on—
It needs a man both strong and stout
These isotopes to sever;
Of this there is no possible doubt,
No probable, possible shadow of doubt,
No possible doubt whatever.

2 So Aston made a cute "machine"
For atom separations.
The atoms passed through fields serene,
Magnetic poles they went between,
And made some marks upon a screen,
Apart from their relations.
The numbers whole were soon made out
By methods neat and clever;
Of this there *was* no manner of doubt,
No probable, possible shadow of doubt,
No possible doubt whatever.

3 Then isotopes of every kind
Grew more in number daily,
And Aston thrust all he could find
Before the harassed and reeling mind
Of a sympathetic but dazed mankind
Most casually and gaily.
The rule of numbers whole to flout
He made his next endeavor;
Of this there's now no manner of doubt,
No probable, possible shadow of doubt,
No possible doubt whatever.

4 Now Christmas time was drawing near,
And as Nobel prize winner,
For Stockholm soon he had to clear,
(Then he followed the trade of a mountaineer),
And now we're all glad we've got him here
To cheer him at our Dinner.
"He's a jolly good fellow!" Then let us shout
In louder tones than ever—
Of this there is no possible doubt,
No probable, possible shadow of doubt,
No possible doubt whatever.

A Biographical Sketch.—This is the last song of which I have cognizance, and the author is to me unknown. "Trinity Council" is the council of Trinity College, Cambridge—the conclave of masters, fellows and scholars—the inner ring of the college. J. J. Thomson was elected a fellow of his college in 1880. (A fellowship meant free room and board for about six years and, I believe, £200 a year as well.) In 1884, at the early age of 28, Thomson was elected Cavendish Professor to succeed the late Lord Rayleigh. An elderly college tutor remarked that "things had come to a pretty pass when mere boys were made professors." Thomson was elected a fellow of the Royal Society in 1884, awarded the Nobel Prize in 1906 and the coveted Order of Merit (there are only twelve O.M.'s in the British Isles), created a knight in 1908, elected president of the British Association meeting in Winnipeg (1909), elected president of the Royal Society in 1915 and Master of Trinity in 1918—and all these events are celebrated in this lively song.

A BIOGRAPHICAL SKETCH

Air: "Bonnie Dundee."

To the Trinity Council the Master thus spoke:
"This here J. J. Thomson's a jolly smart bloke;
Let us make him a fellow without more delay,
For there's no one at all is a patch on J. J.
Come, get up a feast in the Trinity Hall,
And spare no expense on the dinner at all;
Uncork the best port, bring it in on a tray,
And let us all drink to the health of J. J.!"

J. J. is elected, they sit down to eat;
The Master, when finished, gets up from his seat,
And he makes a great speech, and he "ventures to say,
In the future we'll hear a great deal of J. J.
Come, fill up the glasses with wine from the jugs;
Come, empty the alcohol into your mugs;
Get up on your feet with a Hip! Hip! Hurray!
And let us all drink to the health of J. J.!"

He quickly mounts up to the top of the tree
In what is described as "three skips of a flea;"
For they want a professor, and therefore one day
It is duly announced they've appointed J. J.
Come, fill up the lecture rooms, fill up the labs;
The ladies from Girton they drive in in cabs;
The Newnhamites, too, in their usual way,
Fall headlong in love with Professor J. J.

His assistant he asks of him whither he goes?
"I am going to study striations and glows;
For conduction in gases I'm certain will pay
As a field of research," says Professor J. J.

"Come, fit up my tubes; come, fit up my coil;
Come, make me electrodes of platinum foil,
And join up the leads in the requisite way;"
And Everett follows the lead of J. J.

There are centers of learning that give him degrees
In Oxford and Dublin and over the seas,
And diplomas and medals the full of a dray
Are showered on the famous Professor J. J.
Come, look up the list in the current "Who's Who;"
Of the names I can only pronounce very few,
If I made the attempt it would give me away.
So you'd best ascertain how it's done from J. J.

When in due course of time he's created a knight
His splendid court suit is a source of delight,
And when he appears in this gorgeous array
The people all gather to look at J. J.
"Come, rise up, Sir Joseph! Come, rise to your feet!"
Sir Joseph gets up and he beats a retreat;
But his sword rather awkwardly gets in the way
And very near trips up the new Sir J. J.

In the regions far off on Lake Winnipeg's shore
The Advancement of Science leaves much to deplore;
So a meeting's arranged, and of course the B. A.
Decided that the President *must* be J. J.

Come, book up your passages; steamer and rail;
Bring wraps and topcoats, for there may be a gale;
The steamer may pitch and the steamer may sway,
And goodness can tell the effect on J. J.

The Swedish Committee consider it wise
To give Sir Joseph the great Nobel prize;
While our King, as by law, never can go astray,
So he's bound to award the O.M. to J. J.
Come, run up to London; come, run up by train,
And if by good luck it don't happen to rain
Your may bet your best boots on a brilliant display
When the Order of Merit's conferred on J. J.

The Royal Society's Council declare
He is worthy to sit in the President's chair;
While the Trinity Fellows assemble one day
And admit their new Master, the famous J. J.
Come, hurry up now, let us finish this song;
I'm feeling quite thirsty with singing so long;
But, just in conclusion, I wish to convey
Our esteem and affection to jolly J. J.!

J. J. is still with us and addressed the recent meeting of the British Association at Cambridge amid acclamations from all present. May he have a long life yet.

The Stroboscopic Observation of Jets of Water

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THE stroboscopic observation of jets of water[1] provides an exceptionally interesting demonstration for the museum or lecture. The demonstration to be described consists essentially of transmitting a periodic disturbance to a jet of water, thus breaking it into drops; under stroboscopic illumination the succession of drops may be made to appear fixed in position or to move slowly upward or downward in the path of the jet. In order that the motion may be "frozen," it is necessary, of course, that it be periodic; that is, not only must the jet be broken up into drops at a definite frequency, but the drops must have the same shape when at the same position.

The periodic disturbance was produced by means of an electrically driven tuning fork *F*, Fig. 1, clamped to the stand that held the nozzles. Instead of using the contactor, the driving magnet was connected to the 60-cycle supply through a Variac *V*, and the fork was loaded with clamps until its natural frequency of 128 cycle/sec was reduced to about 120 cycle/sec, in order that it could be driven synchronously. The amount and smoothness of the agitation transmitted through the supporting stand could be controlled by varying the load on a platform *P* clamped to the stand. Fair results can be obtained by using a buzzer in place of the

[1] The subject has been discussed in considerable detail by C. V. Boys, *Soap Bubbles and the Forces Which Mould Them* (E. & J. B. Young & Co., 1895); also see, for example, R. M. Sutton, *Demonstration Experiments in Physics* (McGraw-Hill, 1938), p. 103.

fork, or even by mounting an a.c. magnet so that it pulls on the support.

The constant level tank T was used to make the flow uniform. When operating two jets simultaneously the water was fed to the tank through a rubber tube entering from above, thus making both the input and discharge connections on the tank available for supplying the two jets.

Some difficulty may be experienced due to air in the water supply. A nozzle inclined upwards will discharge small bubbles repeatedly, producing a slight irregularity in the stream. If the nozzle is inclined downward, the air will collect in the tube and be discharged only occasionally. The air can, of course, be eliminated by using boiled water in a large supply tank.

If the nozzle is too short or the orifice too small, there is a tendency to form very small drops or a spray, for which the periodicity is poor. Openings of about $\frac{1}{16}$ in. were used and were obtained by drawing $\frac{1}{4}$-in. glass tubes. Since suitable nozzles are not easy to produce, it is suggested that a number be prepared with various openings and the most satisfactory ones be found by trial.

The intermittent illumination for this type of demonstration was, until recent years, obtained by placing a rotating perforated disk in front of a constant light source. However, gas-filled discharge tubes operated by a relaxation oscillator are greatly superior, principally due to the short duration of the illumination. Excellent results were obtained with the General Radio Strobotac separately mounted as shown at S.

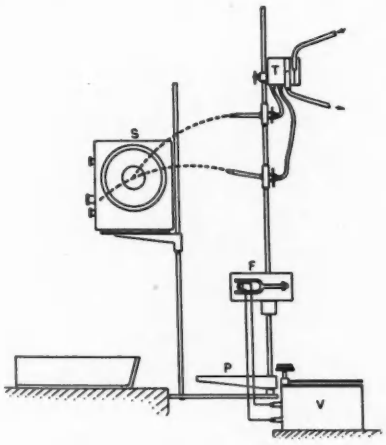

FIG. 1. Diagram of apparatus.

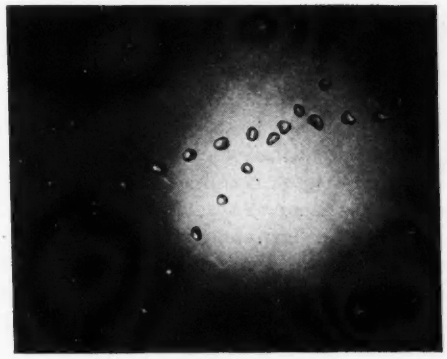

FIG. 2. Photograph of streams from the nozzles.

The best illumination was obtained by mounting the light source on the near side of the jets and using a white reflector as a background. The sharp detail with which the formation of the drops and their subsequent oscillations can be seen, is shown in Fig. 2. This photograph, however, was taken in $\frac{1}{8}$ sec against a background of ground glass illuminated from behind by the Strobotac.

Usually the tail of the forming drop will break off to form one or more small drops which have, in general, a different trajectory than the large ones. An electrified rod, brought near the jet, can be used to prevent these drops from breaking off, or to produce a large distortion of the stream.

An unusual effect is obtained by mounting two nozzles, one above the other, so that the streams meet at some distance from the nozzles. With suitable adjustment the drops in the two streams can be made to pass one another without colliding, so that in white light the jets are seen to interpenetrate without interference. The effect with stroboscopic illumination may be seen in Fig. 2.

The drops can also be made to collide and coalesce into a single stream. It is interesting to note the distortion produced by the collision and the flowing of one drop over the surface of the other.

Some Quantitative Experiments in Elementary Photography

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A FEW quantitative experiments performed in the early part of a course in elementary photography seem to teach the students much more than qualitative experiments which attempt to bring out the same facts. In a course of three semester hours credit, having one four-hour laboratory period and one lecture hour each week, the experiments to be described require a total time of 12 hours in the laboratory with the students working in pairs.

The simplest experiment which is quantitative in character is that of testing the speed of a camera shutter, and two methods which are particularly easy to set up are described here. The other experiments described are designed to give the student a working knowledge of the sensitometric characteristics of various photographic emulsions, and to show how the image sharpness varies for different points in the object space and for various photographic objectives. With the exception of the experiment on the characteristics of photographic emulsions, all of the tests can be carried out with very little special apparatus.

SHUTTER SPEED TESTING

The simplest way to determine the actual speed of a shutter for intervals that are not too short is to photograph the pattern traced out by the glowing plates of a neon lamp operated from a 60-cycle alternating current circuit and moved by hand across the camera field at approximately constant speed.[1] Such patterns are shown in Fig. 1 where the upper figure has 26 plate images, indicating that the lens shutter was open 26/120 or 0.22 sec, instead of the marked 0.25 sec. The lower figure has 57 images of the lamp plates and, therefore, the shutter in this case was open for 0.47 sec.

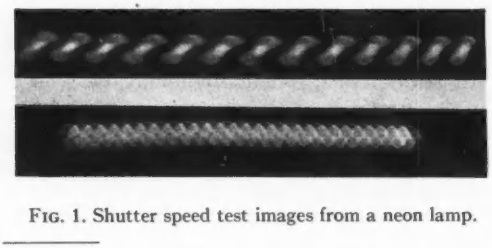

FIG. 1. Shutter speed test images from a neon lamp.

Another method, which is mentioned because of its particular adaptability to home equipment, is that of photographing a rotating phonograph turntable on which a shiny bead has been placed.[2] Knowing the speed of the turntable, which can easily be measured, one can calculate the shutter speed from the length of the arc struck out by the light reflected from the bright bead. (Fig. 2.)

DETERMINATION OF CHARACTERISTIC CURVES

Since the success of any photograph lies in its ability to reproduce, with the desired contrast, all of the tonal gradations in the original, it is advantageous to know the density of silver deposit that will be built up on a sensitive emulsion which has received a measured exposure followed by development for a specific time. In addition, it is desirable to know how the density can be controlled by varying the development conditions. The determination of such exposure, density and development characteristics of

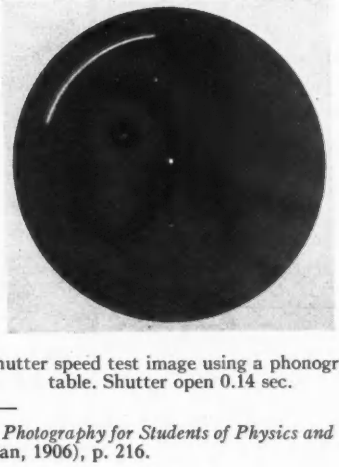

FIG. 2. Shutter speed test image using a phonograph turntable. Shutter open 0.14 sec.

[1] Sheldon, *The American Annual of Photography for* 1936 (Am. Photo. Pub. Co.), p. 241.

[2] Derr, *Photography for Students of Physics and Chemistry* (Macmillan, 1906), p. 216.

photographic materials can be accomplished if the laboratory can provide for: (1) an exact measure of the exposure given to the film; (2) development under carefully controlled conditions; and (3) some method of measuring the density of the developed image.

In this laboratory the students use the rotating disk sensitometer shown in Fig. 3 for exposing strips of film.[3] The disk is 12 in. in diameter and

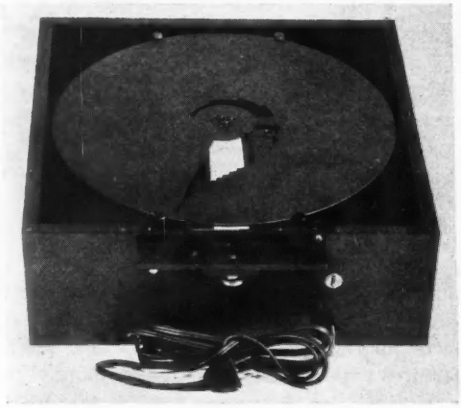

FIG. 3. Rotating disk sensitometer.

its cut-out sector has 25 steps which increase logarithmically with a range of 251, thus giving logarithmic exposure steps of 0.10. The disk is driven by a synchronous phonograph motor through an extra reduction gear and, in addition, a gear shift arrangement makes it possible to drive the disk at either 1/6 or 1/60 rev/sec. A device for covering either half of the film strip allows a long exposure and a short exposure to be made on a single film 1.5 in. wide and 5 in. long, giving a total exposure range of 2510 for the entire strip. For the exposing illumination, the student sets up a standard lamp at a measured distance above the disk and therefore knows the exposure in meter-candle-seconds for each of the 50 steps of the film strip. After development in a controlled bath for a specified time, the strip appears as shown in Fig. 4. Having obtained such strips, the student measures the transmission of each step and determines its

[3] Neblette, *Photography Principles and Practice* (Van Nostrand, ed. 3), p. 181.

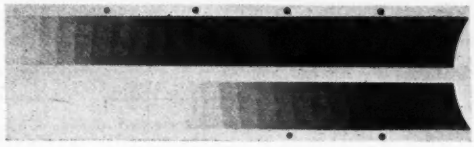

FIG. 4. Sensitometer strip.

density. This can be done on any type of densitometer, but in this laboratory the strip to be measured is placed in the film holder of an enlarger, while the illuminometer shown in Fig. 5 is placed on the enlarger easel. The light transmitted by any one step is then focused on the top of the comparison block B of the meter. The illumination on the side of the block comes from a small standard lamp L in the meter and can be adjusted to match the top illumination by rotating a calibrated variable density wedge W which lies between the meter lamp and the comparison block. A scale on the wedge reads the transmission T at any step when a photometric balance is obtained. Having measured the transmission of all of the exposed steps, as well as the transmission T_0 of the clear film, the student calculates the density of each step above the fog density of the film from the defining equation $D=\log_{10} T_0/T$. These densities are plotted as a function of the logarithms of the corresponding exposures and a characteristic curve results. Each pair of students makes at least two such strips of one kind of film but developed differently, and obtains two or more characteristic curves (Fig. 6) which indicate how the contrast γ and the density are affected by changing the processing conditions. In addition, different types of emulsion are used by different students and, when all of the resulting curves, plotted to the

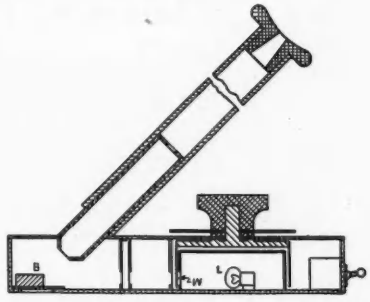

FIG. 5. Diagram of illuminometer type of densitometer.

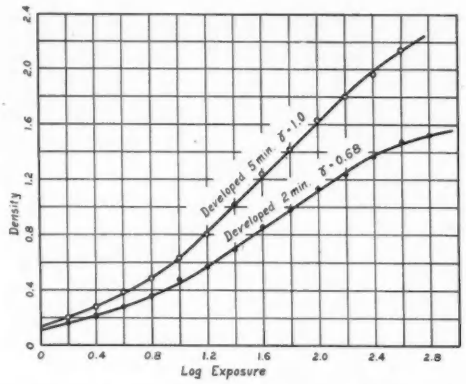

FIG. 6. Enlarging characteristic curves of Supersensitive Plenachrome film developed in D72 at 20°C.

same scale, are posted on a display board in the laboratory, the individualities of any film are observed easily.

It should be pointed out that this method of measurement gives the effective density[4] of the film when used with a particular enlarger, and that this is not the same as the diffuse density sometimes determined by the more experienced students who set up a photoelectric densitometer.

DEPTH OF FIELD AND RESOLVING POWER

A determination of the near and far depth of field[5] and the resolving power[6] of the lens for several apertures gives the students an appreciation of the limitations of the camera and of the importance of choosing the appropriate lens opening for any problem. For this experiment test charts, one of which is shown in Fig. 7, were prepared photographically from a master drawing having various numbers of lines and dots in a distance equal to AA. Charts are made in sizes increasing and decreasing by a factor of 1.04 from a standard-sized chart marked 100 and, if these are set up in slotted blocks at distances from the camera which increase by the same factor, all of the charts give equal-sized images when photographed. This simplifies the calculations since the resolving power for all of the charts on any one negative can be determined

[4] Tuttle, J. Opt. Soc. Am. and Rev. Sci. Inst. **12**, 559 (1926).
[5] Reference 3, p. 89.
[6] Hardy and Perrin, *The Principles of Optics* (McGraw-Hill, 1932), p. 445.

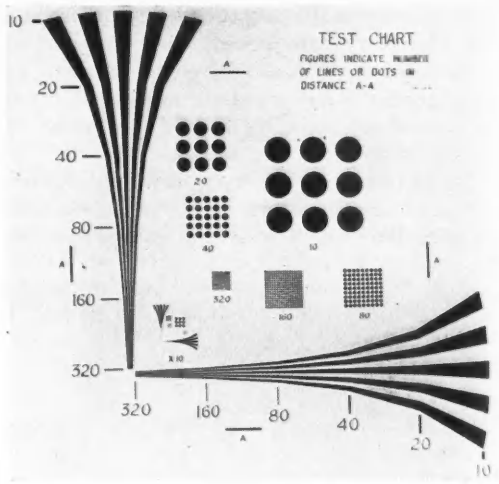

FIG. 7. Test chart.

from a single measurement of the distance AA on that negative. Fig. 8 shows an array of such charts photographed at two different relative apertures with a 5.5-in. Tessar lens focused on a chart 80-in. from the camera lens, and from these the depth of field corresponding to any chosen diameter of circle of confusion is determined by

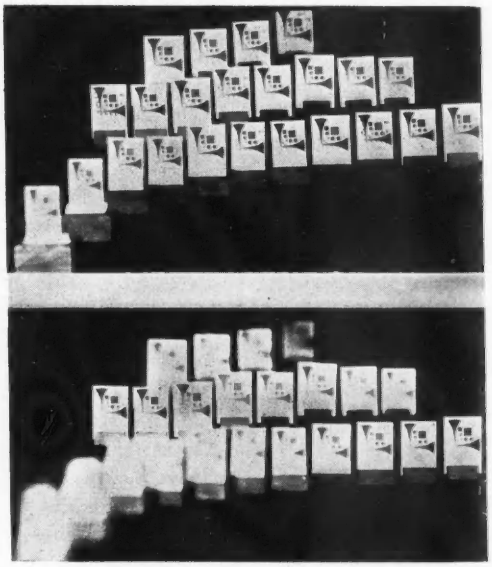

FIG. 8. Depth of field test images at f : 32 and f : 4.5.

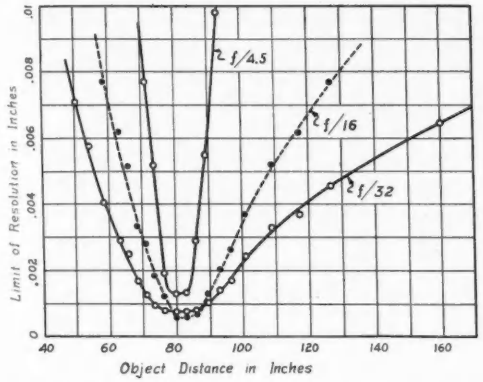

FIG. 9. Depth of field curves for a 5.5-in. Tessar lens.

examining each negative with a low-power microscope to find the nearest and farthest cards that show the maximum allowable limit of resolution. The values thus obtained experimentally for the near and far depth of field at several relative apertures are checked by the student against the theoretical values calculated from the equation $\Delta p = p_0 d(p_0+f)/[f^2/A \pm d(p_0+f)]$, which is derived from ordinary image geometry. Here p_0 is the distance from the lens to the card in correct focus, f is the focal length of the lens, A is the relative aperture, d is the chosen diameter of circle of confusion, and Δp is the near or far depth of field, depending on whether the plus or minus sign is used in the denominator. Even though interpolation between charts is often necessary, the agreement between theoretical and experimental values is very satisfactory.

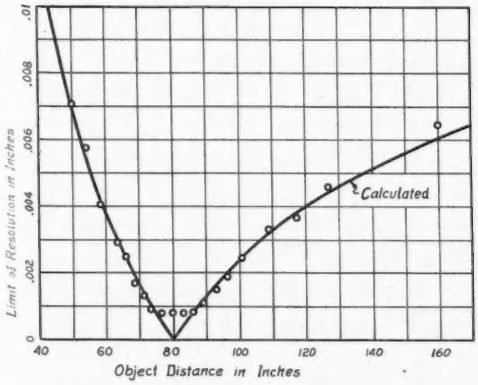

FIG. 10. Comparison of calculated and observed depth of field for a 5.5-in. Tessar lens at f : 32.

The same set of negatives or a similar set made with another lens is used by the students to determine the limit of resolution at any point in the field and for various relative apertures. Taking any negative, for instance, one made at f : 32, the student reads the maximum number of lines per inch which are just resolved on each chart image on that negative. The reciprocals of these values give the limit of resolution or the limiting diameter of the circle of confusion at each chart distance. The limits of resolution in thousandths of an inch are plotted against distances p of the corresponding charts from the lens and when this is done for several apertures a family of curves as shown in Fig. 9 results. The equation $d = f^2\Delta p/Ap(p_0+f)$, derived in the same manner as the one previously given, provides a theoretical check on the experimental values. Such a check is shown in Fig. 10 for a relative aperture of f : 32. This comparison of theoretical and experimental curves helps to impress upon the student that, while the theoretical limit of resolution is zero at the position of correct focus, the practical limit cannot be zero since there will always be some distortion of the image due to lens imperfections and some loss of resolving power due to the nature of the photographic emulsion.

FLATNESS OF FIELD AND ASTIGMATISM

For determining flatness of field and astigmatism the same kind of charts are used as in the previous experiment. Several cards of equal size are set up at 5 degree intervals in a row across the field of view and at a measured distance from the camera which is focused upon the central card. Other rows of cards of the proper size are then set at small distances in front of and behind the first row. A photograph of such an array

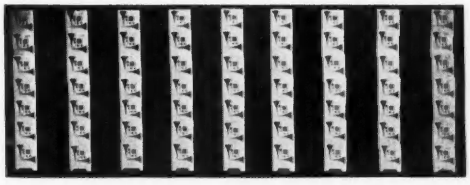

FIG. 11. Lens test image with a 5-in. rapid rectilinear lens at f : 9. The test charts are 68.6, 72, 76, 80, 84, 88 and 92.6 in. from the lens.

taken with a 5-in. rapid rectilinear objective opened to $f:9$ is shown in Fig. 11. The central card is the one in correct focus and, if the field had been perfectly flat, the fourth card up in each vertical column would be the sharpest. The position of maximum resolving power in each vertical column indicates to the student the lack of flatness of field at that particular angle from the central axis.

Figure 11 also shows the effects of astigmatism, since the horizontal and vertical lines of objects removed from the axis of the lens do not appear in equally good focus on any one card.

These experiments seem to give the students a concrete realization of the factors that should govern the choice of a lens, the lens aperture, the kind of film and the development to be used for any prticular photographic problem. The experiments described were chosen because of the ease with which they may be set up and performed, and the utility of the information which is derived from them.

FIG. 1.

Experiments on Torque, Angular Acceleration and Moment of Inertia

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AN experiment second only in importance to that of establishing the dynamical relationship $F=Ma$ is one that demonstrates the validity of the corresponding relationship in the case of rotation; that is, the relation $L=I\alpha$, where, as usual, L represents the torque, I the moment of inertia of the body about the axis of rotation and α the angular acceleration. A number of experiments that show the latter relationship have been devised; yet even the most modern of them involve unnecessary complications which are definitely undesirable for beginners. Specifically, the most generally used method consists in determining the angular acceleration imparted to a disk-axle combination by a weight. Since the weight itself has an acceleration, there is introduced into the calculation of the torque a complication that has nothing to do with the direct objectives of the experiment; moreover, the ordinarily complicated disk-axle-bearings combination does not lead to an easy calculation of the total moment of inertia nor to the precise evaluation of friction, especially if the old method involving the wave-tracing stylus instead of the spark is used.

A method eliminating the foregoing objections, and the rather expensive rotational-inertia apparatus and measuring devices, has been used with satisfactory results by the writer. It consists of determining the linear acceleration of one end A of a rod (Fig. 1) rotating under the action of its own weight about an axle OO' through its other end B. To avoid unnecessary complications due to the variation of the magnitude of the torque, measurements are taken through a small angle when the rod is near its horizontal position.

When the thin rod of length l and mass M is horizontal, the equation $L=I\alpha$ takes the form

$$Mgl/2=(Ml^2/3)\alpha, \qquad (1)$$

where $Ml^2/3$ is the moment of inertia of the rod[1] about the axis OO'. Eq. (1) reduces to

$$3g/2=l\alpha=a,$$

where a is the linear acceleration of the end A of the rod. The experimental verification of the law of rotational motion is therefore reduced in this case to proving that the linear acceleration a of the end A of the rod is $3g/2$, irrespective of the length or mass of the rod.

THE EXPERIMENT

The axle OO' passes through a hole drilled in the end B of the rod and is clamped to a heavy

[1] For an elementary derivation for any thin rod or wire about the axis at B, assume the rod to be divided into n equal parts of mass m each; then

$$I=m\left(\frac{l}{n}\right)^2+m\left(\frac{2l}{n}\right)^2+\cdots+m\left(\frac{nl}{n}\right)^2$$
$$=m\left(\frac{l}{n}\right)^2\{1^2+2^2+3^2+\cdots n^2\}=m\left(\frac{l}{n}\right)^2\left(\frac{n}{3}\right)^3=\frac{Ml^2}{3}.$$

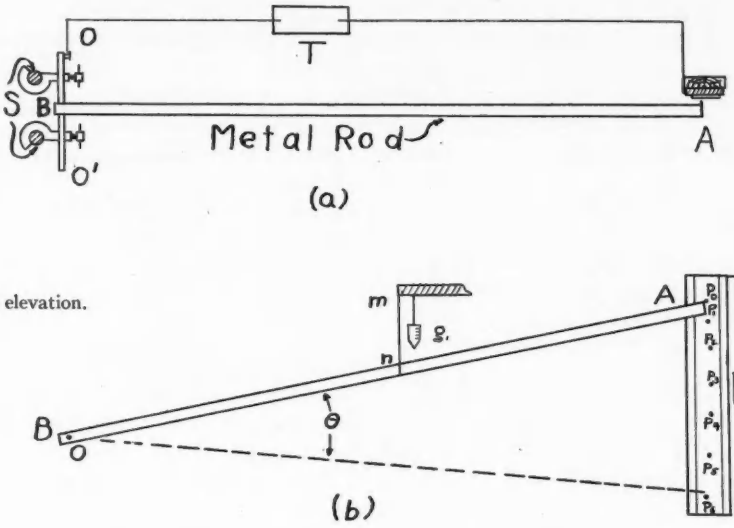

FIG. 1. Apparatus: (a) plan; (b) elevation.

stand[2] S. The rod is initially held in a position slightly above the horizontal by means of a thread mn, Fig. 1(b), attached to a stand. When this thread is burned the rod rotates[3] through an angle θ. The end B is connected through the axle OO' to one terminal of a spark-timer T. To the end A is attached a small spark-discharging stylus, adjusted so that it moves parallel to, and at a distance of about 3 mm from, a strip of waxed paper. This adjustment is simplified by the use of two plumb lines g_1 and g_2. The waxed paper is mounted on a vertical metal strip which is connected to the other terminal of the spark-timer. The marks left on the strip of paper lie on an arc as indicated in Fig. 1(b). From considerations similar to these used for the determination of the acceleration of a freely falling body from a spark record, we have, for example,

$$\text{Distance } (P_6-P_3)-\text{Distance } (P_3-P_0)=a_3,$$

where a_3 represents the linear acceleration expressed in terms of the time interval $3T$, T being the time interval between successive sparks. If we have N spark discharges per second the acceleration a in centimeters per second per second will be $a_3(N/3)^2$. For the timer used, N was 30 and therefore $a=100a_3$ which, by Eq. (2), must be equal to $3g/2$, that is, to 1470 cm/sec^2, irrespective of the length or mass of the rod.

Table I presents some typical data obtained with rods of various lengths, materials, and mass. It is seen that in most cases the error is close to 1 percent. From the averages in the last column and from a similar analysis of a large number of data obtained with rods of various lengths, diameters and rigidities it appears that the error decreases as the rigidity increases. The effect of friction and the fact that the torque-arm of the force is not exactly $l/2$ throughout the rotation are negligible factors. Probably the most important sources of error are the small variations in the period of the spark discharge and in the path taken by the spark.[4] An error of 1 mm introduced by any of these causes, or in the process of measuring the distance between the sparks, means an error of about 0.7 percent in the final result. In the free-fall experiment the effect of accidental errors due to the timing of the spark discharge is considerably diminished because of the larger number of time intervals used. In the present experiment the accidental

[2] A Young's modulus apparatus provides a satisfactory stand, the axle OO' being supported by two heavy clamps.

[3] No serious error is introduced as long as the ratio of the length of the rod to the arc of θ is larger than 4.

[4] This can be diminished by placing a wire along the path of the stylus instead of a metal strip behind the paper or by using especially designed discharge points that are available in the market. Greater precision also is introduced by modifying the design so that the actual axis of rotation will coincide with the theoretical axis.

errors can, of course, be diminished by making several trials, all of which can be recorded on the same strip. Each trial requires about one minute. In the case of a long rod, an additional value of the acceleration can be obtained by using an eighth spark-point. It is advisable, especially when only one spark track is available, to use also the values obtained for the acceleration when two time intervals instead of three are used. In weighing the values obtained we must have in mind that their weight is proportional to the square of the time interval used.

Supplementary Experiments

With small changes, the same apparatus can be used to perform a number of important experiments on the rotation of rigid bodies. That the angular acceleration is proportional to the torque can be demonstrated by keeping the moment of inertia constant while the torque is varied. This can be done easily without varying I by hanging various weights from the rod by a flexible thread as is indicated in Fig. 2(a). In this case we have

$$Mg(l/2)+m(g-a')d=\alpha Ml^2/3,$$

where m is the mass of the hanging weight and a' is its linear acceleration. For the special case in which $m=M$ and $d=l/2$, we have

$$Mg(l/2)+M\left(g-\frac{a}{2}\right)\frac{l}{2}=\alpha Ml^2/3,$$

Table I. *Typical data.*

Rod No.*	(P_6-P_3) (cm)	(P_3-P_0) (cm)	a_2 cm/(sec/10)^2	a (cm/sec^2)	$3g/2$ (cm/sec^2)	Error (per-cent)
1	28.24	13.68	14.56	1456	1470	0.95
	27.32	12.50	14.82	1482	1470	0.82
	27.25	12.50	14.75	1475	1470	0.34
	28.58	13.92	14.66	1466	1470	0.27
						Av. 0.59
2	26.50	11.85	14.65	1465	1470	0.34
	25.67	10.95	14.72	1472	1470	0.14
	30.30	15.83	14.47	1447	1470	1.56
	29.82	15.32	14.50	1450	1470	1.36
						Av. 0.85
3	28.10	13.80	14.30	1430	1470	2.72
	24.65	10.05	14.60	1460	1470	0.68
	26.05	11.50	14.55	1455	1470	1.02
	29.35	14.75	14.60	1460	1470	0.68
						Av. 1.27

* Rod No. 1: metal, $l=149$ cm, $d=1.95$, $M=3278$ gm.
Rod No. 2: wood, $l=136$ cm, $d=2.4$ cm, $M=367$ gm.
Rod No. 3: wood, $l=200$ cm, $A=0.8\times2.5$ cm^2, $M=280$ gm.

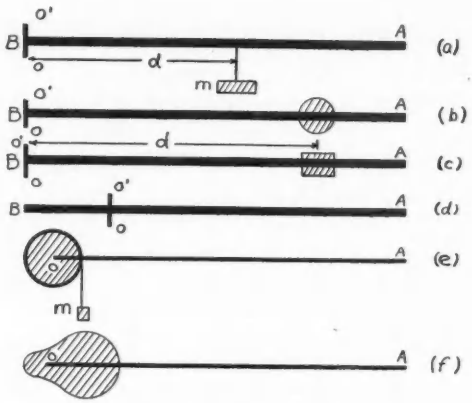

Fig. 2. Supplementary experiments.

from which we obtain for the linear acceleration of the rotating end A,

$$a=12g/7=1680 \text{ cm/sec}^2.$$

Designating by the subscripts *1* and *2* the values of the torque L and acceleration a for the two cases where the hanging weight is absent and present, respectively, we have $L_2=8L_1/7$ and $a_2=8a_1/7$.

In Table II some values of a_1 and a_2 are compared. The values of a_1 were obtained by using a wooden rod of length 148.5 cm, diameter 2.3 cm and mass 450 gm. The values of a_2 were obtained when a weight of 450 gm was suspended from the center of the same rod by means of a long thread. When many values were used the average difference between $8a_1/7$ and a_2 was found to be about 1 percent. The pairing of the values of a_1 and a_2 is based solely upon the fact that they have been obtained from points on the same strip of paper and represent, therefore, the type of results that the students may obtain when using only one set of data.

When it is desired to change I without changing L, an arrangement consisting of a rod

Table II.

a_1 (cm/sec^2)	$8a_1/7$ (cm/sec^2)	a_2 (cm/sec^2)	Difference (percent)
1435	1640	1658	1.1
1442	1648	1650	0.1
1445	1651	1661	0.6
1435	1640	1665	1.5

with two heavy sliding weights can serve the purpose. If the distances of both weights from the center of mass of the rod are made equal and then are equally increased, the moment of inertia increases while the total torque remains constant.

By placing spherical or cylindrical bodies at various distances from the axis of rotation, as in Fig. 2(b) and 2(c), one may demonstrate Lagrange's theorem of parallel axes. A beautiful and simple application of this theorem is obtained if the rod shown in Fig. 2(d) is made to rotate on an axle OO' that is not at the end of the rod. The rotation of a wheel can be studied by means of an apparatus similar to that shown in Fig. 2(e). The rod, which is rigidly connected to the wheel, can be either heavy, in which case it supplies the necessary torque for rotation of the wheel, or light, in which case the rotation can be produced by a suspended weight. The same considerations apply to the study of the rotation of any other body [Fig. 2(f)]. By using two rods of different lengths and mass the conclusion reached theoretically, that the linear acceleration of the free end is constant and independent of the lengths and mass of the rod, can easily be demonstrated.

The experiment described in the first part of the paper has been tested with engineering and premedical students. They prefer this method for its simplicity and directness to the older methods described in laboratory manuals.

The writer wishes to express his thanks to Professor Henry A. Perkins of Trinity College for making important suggestions and criticisms of the manuscript.

The Commission on Examinations in Physics and Chemistry of the College Entrance Examination Board

FOLLOWING the adoption of the higher level examinations in the physical sciences and the biological sciences representing two years of school work, many requests were received by the College Entrance Examination Board for new definitions of requirements in these areas. It is obvious, however, that a solution of the problem of requirements at this higher level presupposes a fundamental reconsideration of the meaning of similar definitions at the one-year level of attainment in physics and chemistry.

Since the present definition of requirements in elementary physics was adopted by the Board in 1921, and the corresponding requirement in chemistry in 1927, a new Commission has been appointed to reconsider the problem of requirements in science. The personnel of the Commission is as follows: Dean John T. Tate, *Chairman*, University of Minnesota; Dr. Otis E. Alley, High School, Winchester, Massachusetts; Mr. Raymond Brownlee, Stuyvesant High School, New York City; Dean Janet H. Clark, University of Rochester; Mr. J. S. Hogg, Phillips Exeter Academy, Exeter, New Hampshire; Professor E. B. Kelsey, Yale University; Mr. Alfred R. Lincoln, Technical High School, Springfield, Massachusetts; Professor Duane Roller, Hunter College; Professor F. W. Sears, Massachusetts Institute of Technology; Professor Mary L. Sherrill, Mount Holyoke College; Mr. Howard A. Taber, Hotchkiss School, Lakeville, Connecticut.

At the initial meeting of the Commission on February 23, discussion revealed widespread dissatisfaction with the older definitions of requirements because of their extended scope. The opinion was expressed that teachers could cover a smaller range of topics more thoroughly and in so doing give more training in genuine scientific method. Committees are now at work discussing the actual details of the suggested decrease in area and increase in depth.

After completing its work at the first-year levels, it is expected that the Commission will turn its attention to the problem of definitions of requirements at the second level.

The Board will welcome suggestions from teachers of the sciences and will gladly transmit communications to all members of its Commission.

CARL C. BRIGHAM

Research and Statistical Laboratory,
College Entrance Examination Board,
Princeton, New Jersey.

NOTES ON APPARATUS AND DEMONSTRATIONS

Telescope Method for Determining the Focal Length of Lenses and Mirrors

ONE of the well-known methods for determining the radius of curvature of a convex mirror makes use of a telescope. The method is fairly accurate and very instructive in principle. In the present note it is extended to lenses.

The method as applied to a convex mirror is explained by Glazebrook and Shaw[1] but for the sake of completeness a brief description is given here. Fig. 1 represents a convex mirror whose center of curvature is at C, and T is a telescope. At AA' is a strip of white cardboard on which fairly black lines have been marked at intervals of 10 cm. The telescope is kept at a distance of about 1 m from the convex mirror, and the image AA' in the mirror is seen through the telescope. An ordinary millimeter scale SS' is placed in contact with the mirror and parallel to AA'. The telescope is alternately focused on SS' and the image of AA', and the number of divisions of the scale SS' that correspond to one division of the scale AA' is noted. If l is the value of one division on the object scale AA', and K is the length of the scale SS' that correspond to one division of the scale AA', then it is easily proved that $r=2aK/(l-2K)$, where a is the distance between the mirror and telescope, and r is the radius of curvature of the mirror.

The extension of this method to a concave (or convex) lens is quite straightforward, if we utilize the principle that a concave (or convex) lens backed by a plane mirror is equivalent to a convex (or concave) mirror of radius of curvature equal to the focal length of the lens.

It may be noted that in the actual experimental arrangement we placed the scales AA' and SS' vertically, and not horizontally as mentioned in Glazebrook and Shaw's book, because the vertical position is much simpler to arrange. A lamp placed in front of the scale AA' facilitates the observations very considerably.

As an illustration, we may quote the following set of observations for a concave lens: $l=10.0$ cm; $k=0.74$ cm; $a=100$ cm; therefore, $f=17.3$ cm.

A variation of the method consists in dispensing with the mirror backing the lens. In this case the scale AA' is placed on one side of the lens and the telescope on the opposite side, the lens being placed midway between AA' and the telescope. The observations are made as before. As can be easily shown, the formula in this case becomes $f=aK/(l-2K)$.

As an illustration the following set of observations for a concave lens may be quoted: $l=10.0$ cm; $k=1.30$ cm; $a=100$ cm; therefore, $f=16.5$ cm.

SUKHDEO BIHARI MATHUR

University of Delhi,
Delhi, India.

[1] *Practical Physics* (1889), p. 339. This method is used by the students in the degree classes at our university and other places to determine the radius of curvature of a convex mirror.

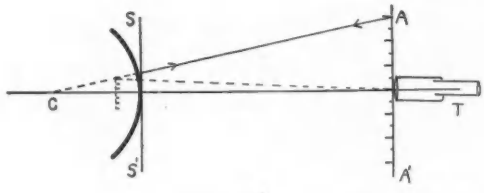

FIG. 1.

The Apparent Bore-Diameter of Transparent Tubes

SEARCH of a number of textbooks of general physics and optics reveals that one of the most easily derived and demonstrated applications of Snell's law does not receive the attention which it deserves.[1] If the apparent inside diameter of a thick-walled cylindrical transparent tube is observed by sighting through the walls, the ratio of the apparent diameter R to the real diameter r is, as is shown by Fig. 1, the index of refraction of the glass. The condition for the relation to hold is illustrated in Fig. 2. When the ratio of the outside diameter of the tube to the inside diameter is equal to the index of refraction, the ray starting along a tangent to the inside cylinder can just emerge at glancing angle and, except for the effect of irregularities in the glass, the tube wall will appear to be of zero thickness. If the ratio of diameters is less than the index of refraction, light starting along such a tangent path will be totally reflected, and it is impossible to make any estimate of the inside diameter by lateral observations.

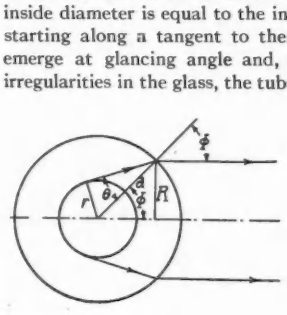

FIG. 1.

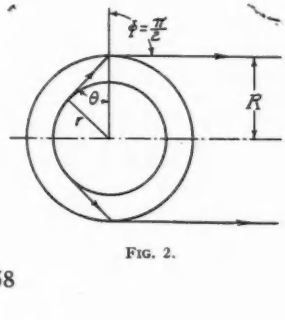

FIG. 2.

This application of the law of reflection is strikingly illustrated if a number of tubes with different diameter ratios are examined. Students are particularly surprised when they are presented with a tube of thickness just below the critical value,

which they judge from lateral observations to be very thin but find, on longitudinal observation, to have a cross-sectional area made up of more glass than bore.

The result, of course, holds as well for a spherical body with a concentric cavity. Observations of commercial Pyrex capillary tubing have shown that the optical properties of the glass are generally sufficiently good so that careful external measurement will enable one to determine the inside diameter to within 1 or 2 percent, even when white light is used and the value of μ_D is assumed for the correction.

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[1] The only reference to this relation which I have found in the literature is in a paper by J. I. Shereshefsky [J. Am. Chem. Soc. **50**, 2978 (1928)], who used it for the measurement of capillary tubes. He states the equation without proof as an "approximate formula."

The Use of a Suspension of Scattering Particles as Optical Analyzer

THIS note describes an interesting variation of the standard arrangement used to demonstrate the interference colors obtained when thin pieces of doubly refracting materials are placed between an analyzer and a polarizer.[1] If a tank of water containing a suspension of scattering particles is used as analyzer,[2] and a thin section of uniform thickness is placed in the path of the light leaving the analyzer, a beautiful beam of colored light is seen by an observer who is looking at right angles to the beam in the tank. By using an inclined mirror,[2] the reflected image is seen in complementary color.

The experiment may be varied in a number of ways. For example, if one uses a polarizer of wide aperture, such as a 4-in. square of Polaroid, and several "windows" of waterproof Cellophane of different thicknesses, corresponding parallel beams in different colors traverse the tank. Or again, if the polarizer consists of two adjacent pieces of Polaroid, placed one above the other, with their line of separation horizontal, but with vibration planes at right angles, adjacent beams in complementary colors are observed when a single window of Cellophane is used.

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[1] R. Sutton, *Demonstration Experiments* (McGraw-Hill, 1938), Exp. L–136.
[2] Reference 1, Exp. L–128.

Lecture-Demonstration of an Ultraviolet Spectrum

THE recent development of high intensity mercury arcs has made possible an interesting and somewhat spectacular lecture-demonstration of an ultraviolet spectrum. The apparatus pictured in Fig. 1. has been in use for about a year. It has proved to be valuable and has elicited many favorable comments.

The apparatus consists of a type-H_3 mercury arc[1] and transformer, a roughly adjustable slit, a planoconvex quartz lens of focal length about 20 cm, mounted so as to be adjustable for focus, and a quartz prism. The mercury arc must have a hole blown in the glass bulb, as described by Winans,[2] in order to obtain the ultraviolet spectrum. The quartz lens need have a diameter of only about 2 cm and a prism 2 cm on a side is sufficient. The cost is low, since neither lens nor prism must be of optically perfect quartz.[3] The prism need not be of the Cornu type, but the light should traverse the prism approximately parallel to the optic axis. The details of construction of the apparatus are obvious from Fig. 1.

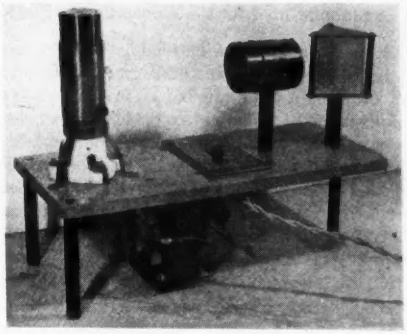

FIG. 1. Apparatus for demonstrating an ultraviolet spectrum.

The spectrum formed by this apparatus is focused on a fluorescent screen,[4] 5 × 24 in., placed at a distance of 10 to 15 ft from the prism. The fluorescence due to the lines between 2536A and the visible region is so brilliant that it can be observed from any part of a room that seats 250 people. If a brighter spectrum is desired, the source slit may be mounted inside the glass tube surrounding the arc, and then larger optical parts can be used with profit. In addition to demonstrating the extension of the spectrum into the ultraviolet, the apparatus can be used also to show the transmission and absorption of ultraviolet by various substances. It can be used to demonstrate to students individually that the line of wave-length 3650A is visible and appears blue rather than violet. The demonstration of the ultraviolet spectrum is used regularly by the writer as an introduction to a discussion of the new fluorescent lamps.

This same apparatus can be used to demonstrate Stokes' law if the lines in the visible portion of the spectrum are used; that is, a screen that emits red light in fluorescence may be excited by the yellow and green lines, whereas a screen that emits blue fluorescent light is not excited by the yellow and green lines, but only by the blue, violet and ultraviolet.

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[1] General Electric Lamp Works, Cleveland; cost of lamp and transformer, $14.
[2] J. G. Winans, Rev. Sci. Inst. **9**, 203 (1938).
[3] A quartz lens and prism for this demonstration may be obtained from Bausch & Lomb, Rochester, N. Y. or Master Optical Co., 19 W. 36 St., New York, N. Y., at a total cost of $15 to $30, depending on the quality.
[4] Fluorescent paint or, preferably, fluorescent gummed paper suitable for this demonstration may be obtained from the Stroblite Company, New York, N. Y.

A Pendulum Timer for the Elementary Laboratory

THE usual method of determining the period of a simple pendulum in the undergraduate laboratory is that of counting a large number of swings of a standard pendulum and determining coincidences between the standard and the simple pendulum. An entire laboratory period is commonly assigned for the determination of the acceleration due to gravity from the period of the pendulum as measured by this method. Several difficulties are encountered by the student. Thus, in order to secure a sufficient number of coincidences, the simple pendulum must be started in a sizeable arc with the possibility that the path may become elliptical and the lower contact miss the mercury cup on one-half of the swing. To remove this difficulty and to obviate the necessity for using a carefully standardized seconds pendulum, the following apparatus was constructed to time the simple pendulum directly and quickly.

As shown in Fig. 1, a double pole, quick-acting relay, operating on 2 v d.c., is used to open and close a 60-cycle a.c. circuit driving a Cenco counter. With push button I closed, the relay closes when the pendulum crosses the mercury contact. Current from battery A passes through one relay-contact and a resistance R_1 to hold the relay closed, while current through the other relay-contact starts the counter. After any *even* number of counted swings, push button II is depressed. When the pendulum now crosses the mercury contact, battery B is connected through resistance R_2 in opposition to A and the current in the relay coil drops nearly to zero, thus opening the relay and stopping the counter. Some care must be exercised in adjusting R_1 and R_2 so that the currents in the two circuits will be approximately equal and also so as to prevent the relay-contacts from vibrating while opening.

The time given by the counter is too small by the amount required for the relay to close, but if some 20 swings are involved the error is generally less than that of measuring the length of the pendulum. Since the counter follows alternations of the 60-cycle current, the time is given to 1/120 sec except for the aforementioned error and for variations in the frequency of the 60-cycle commercial current which limit the accuracy.

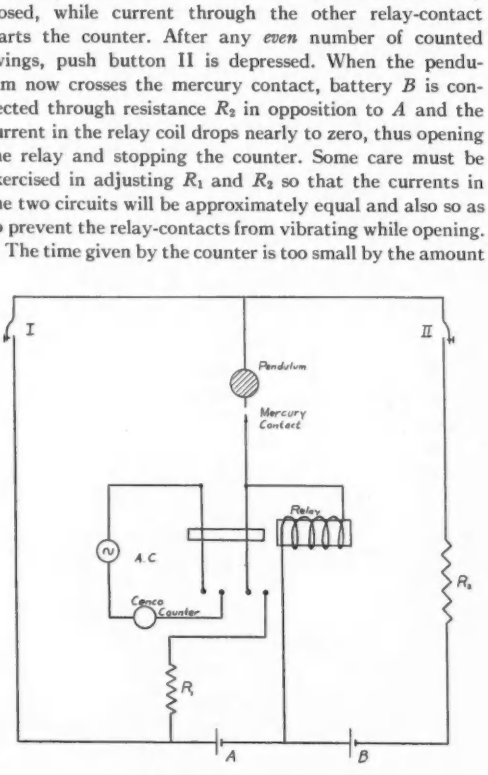

FIG. 1. Diagram of the circuit.

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Concerning Articles on Apparatus for Demonstration and Experiment

THERE are two reasons for writing an article describing a demonstration experiment or piece of apparatus. The first of these is to suggest an idea and the second is to describe the apparatus so that someone else can reproduce it. The purpose of this note is to encourage authors to give more adequate information to achieve the second objective. An expert will have no trouble in setting up the experiment and probably does not even need a description, but the man who is new to the field should be given some help. Even an inexperienced person can make an experiment work, given enough time and patience; but a complete description will save him much time, and encourage him to undertake the experiment.

Too often the attitude of the author seems to be "look at the complicated piece of apparatus that I can make work; now let's see you try." A few details are omitted here and there which "of course," says the author, "everyone should know." This effectively prevents the person building the apparatus from succeeding on the first trial. Circuits in electronics are often given without even the values of the constants. The editor of the *Zeitschrift für Physik* recognizes this kind of difficulty in the theoretical field, and insists that articles in his journal be complete enough so that the difficulties overcome by the author do not have to be overcome again by the reader.

As examples of what might be done to help the reader, diagrams should be fully lettered and each piece of apparatus described in detail. Focal lengths and diameters of lenses, sizes of screens, and distances between different elements of an optical system should be given. It is also a great help to know where the parts may be bought cheaply and what their price will be. Most of this additional information could go in a footnote and would require very little extra space. It takes time to find it out and organize it, but that should be part of the contribution which the article makes to the person expected to build the apparatus.

As a final help to the experimenter, a few tests to tell when the apparatus is working properly and some idea of how it should perform would be useful. For example, if the values of the current and voltage in various parts of electronic circuits were given, the short circuits caused by a splash of superfluous solder could be found more easily.

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Proceedings of the American Association of Physics Teachers

The Stanford Meeting, June 28, 1939

THE second meeting of the American Association of Physics Teachers on the Pacific Coast was held at Stanford University, June 28, 1939, in connection with the 23rd annual meeting of the Pacific Coast Division, American Association for the Advancement of Science and Associated Societies. Vice President A. A. Knowlton presided. The program committee for the meeting consisted of Paul Kirkpatrick, *Chairman*, H. L. Brakel, A. E. Caswell, L. E. Dodd, V. F. Lenzen and E. C. Watson.

The morning and evening sessions, held in Room 372, Physics Department, were devoted to the reading of papers. At noon a luncheon was held in the Garden Dining Room, Stanford Union. Apparatus used in the Stanford University laboratory courses in modern physics and in x-rays were exhibited during the afternoon.

Invited Papers

The following invited papers were heard at the evening session:

The Operational Theory in Elementary Physics. V. F. Lenzen, *University of California, Berkeley, California.*

Historical Viewpoint and Allusion in Physics Teaching. E. C. Watson, *California Institute of Technology, Pasadena, California.*

Some Absolute Experiments for the Electrical Measurement Laboratory, with Demonstrations. R. D. Richtmyer, *Stanford University, California.*

Abstracts of Contributed Papers

Contributed papers were presented at the morning session as follows:

1. Determination of the Gravitation Constant by Students. W. W. Hansen, *Stanford University, Calif.*—General considerations in the design of torsion balances suitable for measuring the gravitation constant by the Cavendish method are discussed, and detailed descriptions of several such balances are given. The latest balance in this series gives a double deflection of about $\frac{1}{3}$ radian and an accuracy, in the hands of students, of better than 1 percent.

2. Unique Classroom Oscillographic Demonstrations. Frank E. Hoecker, *University of Kansas City, Kansas City, Mo.*—The recently developed moving phosphorescent screen oscillograph (Rev. Sci. Inst., May, 1938) permits simple classroom demonstrations of classical electrical phenomena which have heretofore been impossible or impracticable. This instrument plots the curve of emf (or current) *vs.* time on a moving phosphorescent screen, producing curves similar to those of the cathode-ray oscillograph but differing in that the exciting beam does not retrace its original path and the tracing remains easily visible in a darkened room for nearly 1 min. The instrument is used to demonstrate the emf *vs.* time relationship in the classical experiment of withdrawing a magnet from a coil. By suspending the magnet from springs and causing it to vibrate with simple harmonic motion through the coil, various interesting wave forms are demonstrated. The instrument is also used to demonstrate the growth and decay of current in an inductive circuit, the charge, discharge and the damped oscillatory discharge of a condenser, and other familiar electrical phenomena. Recent improvements in design and construction of the instrument are discussed. Slides are shown to illustrate the possibilities of obtaining permanent photographic records when the instrument is used in research.

3. A Model to Demonstrate the Pressures Effective in Deep-Sea Diving. L. E. Dodd, *University of California at Los Angeles, Calif.*—A 25-lb capacity platform scale of the "postal" type, is adapted to read pressures from 0 to 250 lb in.$^{-2}$. Two short lengths of cylindrical rod of cross-sectional area 0.1 in.^{2} are placed vertically with ends opposed. The lower segment is fixed to the platform; the upper one communicates flexibly with a horizontal lever. By placing an object between the two opposed ends it can be subjected to any pressure within the range mentioned. This range corresponds to water depths from 0 to about 600 ft, the latter being the present practical limit for divers breathing ordinary air. The face of the scale is fitted with a specially designed dial that simultaneously reads: (1) pressure in pounds per square inch; (2) pressure in atmospheres; (3) depth in fresh water and (4) depth in sea water. This dial illustrates visually the relation between the two pressure units and the relation between pressure and water depth. It is noticeable that at a depth of 578 ft in fresh water ($p=250$ lb in.$^{-2}$) the corresponding depth for the same pressure in sea water is 15 ft less than this, a distance representing, at that depth, the difference in densities. Incidental to the presentation of the topic, two principal advances in deep-sea diving technic with rubber suits are briefly discussed.

4. An Electric Circuit Containing a Spark Gap. W. P. Boynton, *Whittier, Calif.*—It is assumed that the typical electric spark initially has a superabundance of ions and that these dissipate rapidly, causing the conductance to decrease continuously and vanish in a finite time. To describe the behavior of typical cases, formulas have been devised for conductance, resistance, current and potential, which are either algebraic, ranging from linear to cubic forms, or fairly simple exponentials. The problems considered are the opening of a switch in a noninductive circuit, nonoscillatory and oscillatory discharges of a condenser through a spark gap, and the extension of the latter case to the old spark-type of wireless telegraphy; the circuit breaker of an induction coil and its shunting condenser; and the spark gap carrying a low frequency oscillation or

alternation. The results obtained show a gratifying agreement with available oscillographic records.

5. A Portrait of Edme Mariotte. E. C. Watson, *California Institute of Technology, Pasadena, Calif.*—The complete paper appears elsewhere in this issue.

6. The Principle of Least Action and Other Theorems. A. E. Caswell, *University of Oregon, Eugene, Ore.*—The principle of least action affords the basis for a simple approach to some of the more fundamental theorems of both classical and modern physics. The relations between it, the Hamilton principal function and the Lagrange function are pointed out. A basic energy function is defined and a generalized principle of least action is stated that apply to both conservative and nonconservative systems. A wave-particle postulate is proposed, applying to the ultimate particles, from which the Einstein energy-mass equation, the Lorentz relativity mass equation, the Fermat principle of least time and the de Broglie relation between wave and particle speed are derived. A simple quantum postulate links the Planck constant of action with the principle of least action, and, combined with the foregoing, leads to the de Broglie relation between the wave-length of a particle and its linear momentum. The Schrödinger equation may be derived from this last mentioned relation with the aid of the Hamilton principal function and the differential equation of wave motion.

7. A Simple Device for Demonstrating Relative Specific Heats. Paul R. Gleason and Clement L. Henshaw, *Colgate University, Hamilton, N. Y.*—The development of reversible heat indicator paints has facilitated showing differences in specific heats by means of different rates of cooling of otherwise identical specimens. The necessary conditions are that all the specimens have equal masses, equal surface areas, small internal temperature gradients while cooling, and the same initial temperature, which should be slightly above the transition temperature of the heat indicating paint. These conditions have been satisfied for samples of aluminum, iron, brass and lead by making hollow cylinders of these materials with the same outside dimensions (length $2\frac{1}{2}$ in., diameter $1\frac{1}{4}$ in.) and the inside diameters adjusted to make them all of the same mass. These cylinders are painted with a commercial heat indicating paint, are capped on the ends by a nonconductor to eliminate internal air circulation, and are mounted on an open grille to allow free convection externally. They are heated initially to about 55° or 60°C and set out on the lecture table. The rate of cooling can be increased, if desired, by a gentle breeze from an electric fan. The transition point of the particular paint used is about 45°C, and it changes from brown to green as it cools. The specimens change color at the end of time-intervals that increase with increasing specific heat.

8. Two Experiments in the Building of Plywood Models to Demonstrate Surfaces. Norman Lapworth and L. E. Dodd, *University of California at Los Angeles, Calif.*—Sanded plywood is an inexpensive material for building models to demonstrate the shapes of any physical objects for which one has surface contours available. It is quickly cut to these contours on a band or scroll saw. Uniformity of thickness and easy, precise gluing permit faithful reproduction of surfaces with relatively low expenditure of time and effort. Obviously the method can be used to show interior, as well as exterior, surfaces, in models of the take-down type. The authors have constructed a thermodynamic (van der Waals) surface for demonstration to engineering students, and a set of toric and cross-cylindrical lens surfaces for demonstrations in geometrical optics. The thermodynamic model was built up from contours (isothermals in this case) plotted from the equation for CO_2, applied to 30 equally spaced temperatures that include the critical region; the model is jointed at the critical isothermal, thus permitting it to be opened on hinges to show, drawn on the critical P-V plane, the vapor, liquid-vapor and liquid regions. The toric models, including the solid tore corresponding to them, have marked on them the planes of maximum and minimum curvature, and also a plane at an independently variable azimuth angle.

9. Three-Dimensional Representation of X-Ray Absorption Coefficients. Donald S. Teague and Bradley Burson, *Stanford University, Calif.*—A plot of x-ray mass absorption coefficients as functions of wave-length and atomic number has been constructed by sawing curves out of $\frac{1}{8}$-in. Masonite Presdwood and spacing them about $\frac{1}{8}$ in. The horizontal dimensions are 40×20 in. with a maximum height of about 25 in., representing a scale of 1 in. = 1A for the wave-length range 0 to 4A, and 1 in. = 100 $cm^2\ gm^{-1}$ for the absorption coefficients (plotted vertically). New empirical absorption formulas and numerical values furnished by S. J. M. Allen were used, and additional values needed were obtained by interpolation. The resulting model has definite pedagogic advantages over the usual two-dimensional representations of data in this field. The methods used in construction are widely applicable.

10. An Early American Manual of Electromagnetism. Alfred Romer, *Whittier College, Whittier, Calif.*—Seven years after Oersted's announcement, there was published a manual of experiments and brief treatise on electromagnetism and thermoelectricity: *Electro-magnetism: . . . By Jacob Green,* M.D. *Professor of Chemistry in Jefferson Medical College . . . Philadelphia: . . .* 1827. It was based on Green's class lectures and illustrated with plates of his apparatus, which was made for him in New York. According to the Preface, it was compiled from original papers in the journals. Indeed, though exact references are seldom given, 51 authors and 7 journals are named in the text. It contains descriptions of the standard experiments on the attraction of iron filings to a conductor, the magnetization of iron, the deflections of magnetized needles and conducting circuits. Mathematical treatment is deliberately avoided, but the book is rich in descriptions of electromagnetic apparatus for producing rotation, including some whose currents are thermoelectric. A section is devoted to the multiplier or galvanometer and to experiments which had been performed with it. Thermoelectric phenomena are included as electromagnetic, and described

for the most part as belonging to thermomagnetism. It is interesting to notice the attention paid to problems then unsolved—electrical resistance, the measurement of current, the nature of heat, the source of the earth's magnetism. The book closes with 6 appendixes on a wide variety of subjects.

11. Some Achievements in Electron Optics. L. E. Dodd, *University of California at Los Angeles, Calif.*—Ever since the electron has been known to exist, and to be subject to deflection by electric and electromagnetic forces, the possibility of electron optics has been present. Yet this new field is less than 15 years old. Its growth has been rapid, the literature is already extensive, and it is now an important part of both electronics and optics. Particularly striking is its parallelism with geometrical optics, a subject which has proved to be a ready tool for the analytic development of the new field; this analytic development in turn has stimulated and directed the experimental growth. On the more practical side, electron optics, particularly as found in the electron microscope, has achieved much and promises more. Considerable progress has been made in the knowledge and correction of electron-lens aberrations corresponding to such defects as distortion, astigmatism and coma in optical lenses. The achievements of the optical ultraviolet microscope in photographing biological tissues has been equaled, with promise of further advance. The theoretical resolving power is very high.

12. The Law of Electromagnetic Induction. W. V. Houston, *California Institute of Technology, Pasadena, Calif.*—Many formulations of the law of electromagnetic induction are inadequate for the treatment of all problems, in particular those classified as unipolar induction; the conception of the change of the total flux through a circuit is inapplicable in such cases, and the idea of a conductor cutting the lines of force leads to confusion when the sources of the magnetic field may be moving. A general formulation can be given on the basis of the fact that the electric and magnetic fields at a point depend not only on the coordinates and the time but also on the motion of the coordinate axes with reference to which they are measured. The transformation of the fields from one set of axes to another can be derived on the assumption that the Maxwell equations are valid for all sets of axes and they are a low velocity approximation to the Lorentz transformation equations of special relativity. In addition to providing an adequate conceptual basis for the treatment of all electromagnetic problems, this formulation represents a point of view that needs no revision for the treatment of the theory of relativity.

13. A Course in Electronics as Training in Research Methods. Marcus O'Day, *Reed College, Portland, Ore.*—The numerous possible electronic devices which can be designed for either purely scientific or practical ends afford an unusual opportunity for student adventure into research fields. Problems may be isolated that are small enough and concrete enough to be brought to a conclusion in the time available without undue interference with ordinary instructional needs.

Activities of Association Chapters

Chicago

MEMBERS of the Chicago chapter and other teachers of physics from the Chicago schools and from colleges and universities in the Middle West were guests on May 20, 1939 of Dr. Paul Klopsteg and the Central Scientific Company at the Chicago plant of the Company. Professor William S. Webb, of the University of Kentucky, addressed the group on *Cultural Courses in Physics*. This was followed by a general discussion of the cultural course which Professor Webb has given for many years at the University of Kentucky, and a discussion of the relation of secondary school and college physics. After a tour of the plant of the Central Scientific Company, a luncheon was served at the Belmont Hotel, at which Professor Webb described the archeological work that is being carried out under his direction by the Tennessee Valley Authority.

District of Columbia and Environs

SIXTY-FIVE members and guests attended the annual meeting of the District of Columbia and Environs Chapter, held at Georgetown University on April 1. Professor Thomas B. Brown, president of the chapter, presided. The following papers were presented at morning and afternoon sessions.

Demonstration of a 400-MC Oscillator. Thomas B. Brown, *George Washington University.*
Melde's Apparatus Stroboscopically Illuminated. George D. Rock, *Catholic University.*
Measuring the Ability of High School Students to Apply Physical Principles. W. A. Kilgore, *Central High School, Washington.*
One Method of Meeting Individual Differences in High School Physics. G. Koehl, *McKinley High School, Washington.*
Comparison of the Teaching of Physics on the College Level in the United States and Europe. E. Teller, *George Washington University.*
The Laboratory in the Arts Course. Francis I. Brady, *Georgetown University.*
Comparison of I. Q. and Achievement in High School Physics and Mathematics. Richard L. Feldman, *Roosevelt High School, Washington.*
A Units Chart. Glenn F. Rouse, *American University.*
The Problem of Interesting More Students in Physics. Vola P. Barton, *Goucher College.*
A Modern-Physics Laboratory Course. F. L. Talbot, *Catholic University.*
Pre-Course Tests in College Physics. R. J. Seeger, *George Washington University.*
Ultrasonics as a Teaching Aid. F. E. Fox, *Catholic University.*
Demonstrations with the Stroboscope. John S. O'Conor, *Woodstock College.*
Weighing Air Without a Balance or Vacuum Pump. Ralph B. Kennard, *Wilson Teachers College.*
Common Misconceptions Regarding the Effect of High Frequency Currents on the Body. H. M. O'Bryan, *Georgetown University.*

Other features of the meeting were a tour of the seismological laboratory of George Washington University, conducted by the director, Frederick W. Sohon; an exhibit prepared by the American Instrument Company, the

Spencer Lens Company and the Bausch and Lomb Company; and a luncheon and a dinner.

Officers for next year were elected as follows: George D. Rock, Catholic University, *President;* Glenn L. Rouse, American University, and Thomas B. Brown, George Washington University, *Executive Committee;* and Richard L. Feldman, Roosevelt High School, *Secretary-Treasurer.* The new president, Professor Rock, will represent the chapter on the executive committee of the Association.

Kentucky

CONVENING with the Kentucky Education Association at the University of Louisville on April 14, the Kentucky Chapter of the American Association of Physics Teachers sponsored the following program of special interest to teachers of secondary school physics:

Lecture-Demonstrations. J. G. Black, *Morehead State Teachers College.*
Projects in High School Physics. Paul W. Thurman, *Bryan Station High School,* and E. W. Kirk, *Daviess County High School.*
Physics for Girls. Mary J. McQuire, *Henry Clay High School.*
Radio in the High School. T. M. Hahn, *University of Kentucky.*

Professor O. T. Koppius, President of the chapter, spoke at a luncheon meeting.

The Vice President of the chapter is Professor R. B. Sawyer, Centre College, the Secretary-Treasurer, Professor Guy Forman, Western Kentucky State Teachers College, Bowling Green, Kentucky.

Meeting of the Southeastern Section of the American Physical Society

THE fifth annual meeting of the Southeastern Section of the American Physical Society was held at the University of Georgia on March 31 and April 1, 1939. Dr. Detlev W. Bronk, Director of the Johnson Foundation for Medical Physics, appeared as guest speaker in a symposium on biophysics; his subject was "The Physical Basis of Biological Organization." More than 50 papers were presented at the various sessions, and approximately 150 members and guests registered at the meeting.

The newly elected officers of the Section for the year 1939–40 are: B. A. Wooten, University of Alabama, *Chairman;* R. C. Williamson, University of Florida, *Vice Chairman;* Philip Rudnick, Vanderbilt University, *Secretary;* W. S. Nelms, Emory University, *Treasurer;* N. F. Smith, The Citadel, *Member of Executive Committee.*

Abstracts of papers relating to the instructional and cultural aspects of physics which were presented at this meeting appear below. Abstracts of papers on physical research will appear in the *Physical Review.*

Abstracts of Contributed Papers

1. Some Remarks on the "Cybotactic" Theory. Waldemar Noll, *Berea College.* (By title.)

2. Applied Physics in Medical Practice. Oscar R. Troje, *Tennessee Coal and Iron Company.*—Two instances selected from personal experience are presented to show that even a superficial and nonmathematical knowledge of physics can be of great value in assisting in the solution of problems constantly arising in the modern practice of medicine. The one case deals with pelvimetry and its numerous modifications and adaptations; the other, with a problem arising in oxygen administration. Many other cases could be cited but these two simple problems and their solutions should suffice to bring out more clearly the important relation that "non-hyphenated" physics bears to medicine. It is believed this relationship has been more or less overlooked.

3. On the Passage of Polarized Light through a Crystalline Plate. Philip Rudnick, *Vanderbilt University.*—A statement is presented of a theorem due to Poincaré that is very useful in describing and calculating the modification in the state of polarization produced when light passes normally or nearly so through a plane-parallel plate cut from an optically active crystal. The theorem applies to incident polarization of arbitrary sort, and to any type of double refraction, whether the two component beams are linearly, circularly, or elliptically polarized. If the possible shapes and orientations of the polarization ellipse are represented by the points on a sphere (including linear and circular polarization as special cases), then a simple rotational displacement on this sphere will represent the effect of double refraction.

4. Adiabatic Elasticity and Thermodynamics. L. G. Hoxton, *University of Virginia.*—Attention is directed to the rather widespread practice in texts on thermodynamics of using the first and second laws to prove the familiar relation (Reech's theorem) connecting the adiabatic and isothermal elasticities of a fluid with its specific heats at constant pressure and at constant volume; whereas the theorem may be, and has been, proved without the formal aid of these laws. Two companion theorems are treated by the same method.

5. The Building Program for Physics and Astronomy at the University of Mississippi. W. L. Kennon, *University of Mississippi.*—Under a P.W.A. grant, $136,000 has been made available for constructing and equipping a physics building and observatory at the University of Mississippi. The physics building, of reinforced concrete with brick and tile, consists of 2 stories and a basement, and has 18,000 ft^2 of floor space. The observatory unit will have 2 domes, one of which will house the 15-in. refractor. The entire program is expected to be completed in time for the session of 1939–40.

6. The Importance of Physics in the Study of Geophysics. A. J. Westland, *St. Louis University.*—It is

scarcely necessary to stress the importance of physics in the study of geophysics when the latter is considered in the broadest sense as the "physics of the earth." After briefly outlining the divisions of the science adopted by the American Geophysical Union, the author discusses two branches: seismology and geophysical prospecting. That seismologists and geophysical engineers need a solid foundation in general and advanced physics may be judged from the current literature and text-books, from the courses prescribed in departments of geophysics, and from the opinions expressed by men engaged in geophysical research and commercial prospecting.

7. Physics as a Cultural Course in Women's Colleges. MARY HELEN DODD, *St. Mary's Junior College.*—A discussion of the growing need for, and importance of, cultural courses in physics designed primarily for the nonscience major.

8. Simplified Apparatus for Boyle's Law and Charles' Law. C. R. FOUNTAIN, *George Peabody College for Teachers.*—A sealed capillary tube nearly 1 m long contains about 30 cm of mercury and enough very dry air to occupy a 10-cm column when under the full pressure of 30 cm of mercury. To study the variation of V with P, the tube is mounted on a meter stick, one end of which is clamped to a vertical support. By tilting the tube with respect to the vertical, the pressure, measured by the vertical component of the mercury column, may be decreased enough to allow a 5-fold increase in V; this permits tests of the law over a much greater range than is possible with other simple apparatus, and it is unnecessary to add unseen atmospheric pressures. By placing the tube in deep vessels of water at various temperatures, the thermal expansivities of air at different temperatures can be determined. In making the tube, great care must be taken to exclude moisture or other vapors.

9. Mechanical Method of Showing Alternating Current Phase Relations. WALDEMAR NOLL AND WILLIAM NICKELL, *Berea College.* (By title.)

10. The Application of the Cenco-Evans P.E.D. Set to Routine Experiments on Generators and Motors. SANFORD C. GLADDEN, *University of Mississippi.*—The Cenco-Evans P.E.D. set was designed originally as a demonstration unit. After obtaining information on the field turns from the manufacturer, it has been found possible to procure quantitative data for plotting all of the characteristic curves of d.c. generators and motors. Some of the 8 experiments regularly performed with the apparatus are illustrated with typical student data.

11. The Fourth Dimension in Electrical Theory. HORACE M. TRENT, *Mississippi State College.*—Mechanical quantities are represented by 3 dimensions but 4 dimensions are needed to represent electrical quantities. Five rules are suggested which should govern the choice of dimensions. In brief, they call for simplicity, utility, use of at least one vector and preferably only one, integral powers, and universal agreement on method of measurement. The three mechanical units should be retained and only the fourth should be a purely electrical quantity. In the light of the rules proposed, charge is chosen from a list of 6 scalar quantities as being best for the fourth dimension. A chart is presented that shows the size of units required to form the usual electrostatic, electromagnetic and practical systems.

12. Acoustics as a Required Course for Music Students. R. I. ALLEN, *John B. Stetson University.*—For several years the author has conducted a course on the *Physical Basis of Music* for students in the Conservatory of Music. Initially it was offered as an elective, but the Director of the Conservatory has proposed to make it a required course. As no text has been found which is entirely satisfactory, considerable experimentation has been necessary to determine the content of the course. In addition to the basic principles of sound, topics given special emphasis include the various scales (just, tempered and quarter-tone), the use of the oscillograph in analyzing wave form, and the physical principles involved in each musical instrument. Among the pieces of equipment designed and built for the course is an experimental organ that employs 3 similar sets of pipes, a special keyboard containing double the number of keys ordinarily used, and other special features.

13. An Apparatus for Classroom Demonstration of Lissajous Figures. ALVIN W. HANSON, *The Citadel.*—The apparatus consists of two mutually perpendicular slits which can be made to move with simple harmonic motion. The amplitude and the phase of each slit, and the frequency of one slit, can be varied. The driving mechanism is a Central Scientific Company friction drive rotator. An image of the intersection of the two slits is projected on a screen and can be easily seen by a large class.

14. Some Demonstrations of Vibration. SCHUYLER M. CHRISTIAN, *Agnes Scott College.*

15. A Demonstration of the Schilling Acoustic Experiments for Teaching Optics. E. N. MCWHITE AND C. W. EDWARDS, *Duke University.*—A series of demonstrations with the equipment described by H. K. Schilling in Am. Phys. Teacher **6**, 156 (1938) and **7**, 70 (1939).

16. Extension of Physical Principles to Social Sciences and to Biology. A. A. BLESS, *University of Florida.*—Physical laws and generalizations may be applied qualitatively to social situations if the physical concepts are made so general as to include their social analogies. While these generalized concepts lose much of their physical precision, they are by no means as vague as were the physical concepts themselves before the time of Galileo. With study and generalization, physical laws may possibly become as useful in other domains as they now are in physics. The application of the laws at present are not much more than an analogy because of lack of proper data.

The annual meeting in 1940 will be held at The Citadel, Charleston, South Carolina.

RECENT PUBLICATIONS AND TEACHING AIDS

First-Year and Intermediate Textbooks

Introduction to Physical Optics. Ed. 2. John Kellock Robertson, Professor of Physics, Queen's University, Kingston, Canada. 487 p., 7 plates, 15 tables, 227 fig., 14×22 cm. *Van Nostrand*, $4. This well-known intermediate text appeared first in 1929. The present issue, which is the third printing of the 1935 edition, differs from the edition of 1929 mainly in that errors have been corrected, faulty diagrams have been replaced and changes arising from recent advances have been made. Material has been added on optical methods of measuring the speed of light, polarization by Polaroid plates, doublet and triplet series relations, the vector model of the atom and interpretation of multiplet structure, and the spectroscopic importance of isotopes.

Introduction to Mechanics and Heat. Ed. 2. Nathaniel H. Frank, Associate Professor of Physics, Massachusetts Institute of Technology. 400 p., 137 fig., 15×23 cm. *McGraw-Hill*, $3. Intended for use in the first half of a two-year course in basic, general physics, this textbook on mechanics, acoustics and heat first appeared in 1934. In the present edition, the general order and logical unity characteristic of the original treatment have been left unaltered, but a number of topics have been rewritten with consequent improvement of exposition. The chapters on the kinematics of a particle and static elasticity have been recast and expanded to advantage. Improvements have also been made in the treatments of circular motion, constrained and nonconstrained motion, potential energy, simple harmonic motion, angular momentum, wave motion and other topics. Many of the problems are new.

Atomic Structure. Leonard B. Loeb, Professor of Physics, University of California. 462 p., 111 fig., 7 tables, 15×23 cm. *Wiley*, $4.50. This textbook for a 3-credit, intermediate course is designed to provide physical science students with the basis for courses in quantum mechanics and advanced atomic theory, and to prepare engineering students for work in the fields of electronics and discharge in gases. The author develops his subject on an essentially experimental and historical basis, for he believes that the student cannot be introduced properly to the subject directly from the quantum mechanical point of view but must grow into the use of modern methods in much the same way as have the physicists who developed them. The first five chapters of the book deal with early discoveries and the prenuclear atom; the next six, with the nuclear atom, including the wave mechanical vector model; the next seven, with electrical properties of atoms; and the last but one, with the kinetic nature of a gas. Because relatively elementary treatments of the electron theory of metals are scarce, a final chapter has been included on the Lorentz, classical theory and the modern wave mechanical theory of the metallic state.

Advanced Textbooks and References

Introductory Quantum Mechanics. Vladimir Rojansky, Professor of Physics, Union College. 554 p., 112 fig., 18 tables, 15×23 cm. *Prentice-Hall*, $5.50. A clear and relatively comprehensive introduction to the simpler physical aspects, mathematical methods and formulations of quantum mechanics is furnished by this carefully planned text for upper-division and graduate students. A knowledge of ordinary differential equations is assumed, the additional mathematics needed being treated in two chapters of the text. Nine chapters are devoted to problems in one-dimensional motion as treated by the classical, wave, momentum, matrix and symbolic methods. The remaining three chapters deal with the extension of the wave method to three-dimensional motion, and with the Pauli and Dirac theories of electron spin. Not much stress is placed on applications of quantum mechanics, there being no discussion of the structures of atoms more complex than hydrogen, of molecules, or of the solid state. Many drill-exercises and problems are provided.

Ultrasonics and Their Scientific and Technical Applications. Ludwig Bergmann, Professor of Physics, The University of Breslau. Tr. by H. Stafford Hatfield. 273 p., 148 fig., 24 tables, 14×22 cm. *Wiley*, $4. The ultrasonic frequency range begins at about 2×10^4 vib sec^{-1}—the limit for the human ear—and now extends to 50×10^4 vib sec^{-1}—the limit with present methods of generation, a limit corresponding to wave-lengths of the same order of magnitude as those of visible light. In the ultrasonic region the laws valid for the audible region still hold, but often may be investigated there with increased facility, because of the shorter wave-lengths involved; and new phenomena also have been found that had not previously been observed with the lower, audible frequencies. Although the field is comparatively new, the present book lists some 600 papers, monographs and books; and it is with a general account of the present position, chief results and applications of this research, particularly the experimental work, that the book is concerned. The main topics treated are ultrasonic generators, detection and measurement of ultrasonic waves, speed and absorption of the waves in matter, determination of elastic and elasto-optical properties of solids, and various other applications and effects of ultrasonics.

Modern Magnetism. L. F. Bates, Professor of Physics, University College, Nottingham. 350 p., 97 fig., 17 tables, 14×22 cm. *Cambridge Univ. Press* and *Macmillan*, $4.50. The author of this text believes that the average advanced

student finds far more difficulty in acquiring a satisfactory knowledge of magnetism than of any other branch of physics, and this partly because the subject is usually treated far too much from a strict theoretical standpoint; some of the most important experiments whose results are frequently used in theoretical discussions have not even been adequately described in English. In the present book, therefore, the author not only gives an account of modern magnetic theory but emphasizes fundamental experiments, and includes much other material gained from an obviously exhaustive study of widely scattered literature. The main topics treated are: fundamental concepts, production and measurement of magnetic fields, susceptibility measurements with isotropic substances (an especially noteworthy treatment), magnetic properties of crystals, experiments with single particles, nuclear spins and magnetic moments, gyromagnetic effects, magnetic saturation and equation of state, energy changes associated with reversible magnetization, and magnetostriction. Discussions of galvanomagnetic and most magneto-optic phenomena are excluded because of limitations of space. No problems or exercises are provided.

School Physics

Science Experiences with Inexpensive Equipment. Carleton John Lynde, Professor of Physics, Teachers College, Columbia University. 271 p., 215 fig., 13×20 cm. *International Textbook Co.*, $1.60. The first book of this series [Am. Phys. Teacher **5**, 237 (1937)] described 200 simple physical experiences for grade children that can be had with home equipment. The present book describes and explains 85 new experiences that require only home equipment, and 115 simple experiments that make use of additional, but inexpensive, apparatus.

Essentials of Alternating Currents. William H. Timbie, Professor of Electrical Engineering and Industrial Practice, Massachusetts Institute of Technology, and Henry H. Higbie, Professor of Electrical Engineering, University of Michigan. 387 p., 249 fig., 10 tables, 12×18 cm. *Wiley*, $2.25. Designed as a text for practical courses given in trade, industrial and technical high schools, this book deals competently but in simple language with the information and problems of alternating-current practice that an electrical worker is most likely to meet in his trade. The present edition, a completely rewritten version of the 1919 edition, was prepared by Professor Samuel H. Caldwell, of Massachusetts Institute of Technology. It includes new material on methods of starting and protecting a.c. motors, static condensers for power factor correction, rectifying devices, and the small capacitor household motor.

Science Education

Third Digest of Investigations in the Teaching of Science. Francis D. Curtis, Professor of Secondary Education and the Teaching of Science, University of Michigan. 429 p., 100 tables, 13×19 cm. *Blakiston's*, $3.50. The present volume of this series contains factual digests of 94 selected investigations, made during the period 1931–37, of various aspects of science teaching on the elementary, secondary and college levels. Many other educational studies made during this period, but not digested here, are listed in a classified bibliography.

Investigations of Vocabulary in Textbooks of Science for Secondary Schools. Francis D. Curtis, Professor of Secondary Education and the Teaching of Science, University of Michigan. 135 p., 28 tables, 15×23 cm. *Ginn*, $1.40. The results of 99 studies of the vocabularies found in secondary-school science textbooks are described in this monograph. Some of the general conclusions are that: (1) more than twice as many of the uncomprehended technical and nontechnical words encountered by students in science textbooks belong in the seventh 1000-word level of Thorndyke's *Teacher's Word Book of 20,000 Words* as belong in the sixth or any preceding level; (2) the difficulty which senior high-school students experience with vocabulary is due as frequently to nonscientific as to scientific words, and this difficulty could be lessened by confining nontechnical vocabulary largely to the words in the first six 1000-word levels of the Thorndyke list; (3) too many scientific words are left undefined; (4) many terms are not defined the first time they appear; (5) there is insufficient provision for repetition of difficult terms; (6) it is not enough merely to define a term the first time it appears, and hence a glossary including definitions and pronunciations of the most important terms should be provided. The author presents lists of terms suitable for such glossaries.

Miscellaneous Books

A Hundred Years of Chemistry. Alexander Findlay, Professor of Chemistry, University of Aberdeen. 352 p., 10 fig., 5 tables, 13×21 cm. *Macmillan*, $4.25. The author has provided a readable but serious, documented account of the developments of chemistry, radioactivity and atomic constitution, beginning with the work of Liebig and Wöhler about 1830, which laid the first sound foundation for a theory of organic compounds. Modern quantum theory is not included in the account of very recent developments. Two of the 13 chapters deal with industrial chemistry. Biographical sketches of the most eminent contributors to chemical science during the period appear in an appendix.

Lecture Experiments in Chemistry. G. Fowles, Latymer Upper School, Hammersmith, London. 580 p., 150 fig., 14×21 cm. *Blakiston's*, $5. Lecture experiments in the teaching of elementary chemistry are dealt with comprehensively in this book, which describes 547 qualitative and quantitative experiments. Instructions for carrying out the experiments are given in detail, and many suggestions are included concerning such matters as the interpretation of results and the better exposition of difficult points. The introductory and closing sections deal with aims and methods in teaching chemistry, the relation of lecture experiments to the rest of teaching, the general technic of demonstration, and divers mechanical aids to lecturing, such as projectors and charts.

Charts and Posters

Clouds. 51×66 cm. *U. S. Weather Bureau* (Supt. of Documents, Washington), 5 cts. Twelve halftone plates grouped together on a poster.

Periodicals

Bell Laboratories Record. *Bell Telephone Laboratories* (Director of Publications, 463 West St., New York). A monthly journal devoted mainly to articles on electric communication and the underlying sciences. Although the journal is generally available on a subscription basis the Laboratories will send it gratis, upon request, to physics departments or general libraries of colleges in the United States.

Pamphlets

General Electric Motion Pictures. *General Electric Co.* (Visual Instruction Sec., Schenectady, N. Y.), gratis. A catalog describing 97 sound and silent films on physics, engineering, transportation, industries, etc., that may be borrowed or purchased from the General Electric Co.

Suggested Specifications for Electrical Laboratory Equipment. Rotaprint 841. *Westinghouse Electric and Manufacturing Co.* (Dept. 5N, East Pittsburgh, Pa.), gratis. Designed for the use of educational institutions in preparing specifications for new electrical laboratory installations or enlargements of existing facilities, this booklet provides specifications for all equipment from incoming lines to tools, and includes a list of experiments that might be carried out with the apparatus.

Film Slides

Principles of Physics. 35-mm safety film. *Visual Sciences* (Suffern, N. Y.), $2 per roll or $12 per set. Seven rolls of films containing diagrams designed primarily for secondary school instruction and dealing with mechanics I, mechanics II, heat, sound, light, magnetism, and electricity, respectively. Also available are film-slides on optical illusions and on the history of clocks and watches, and a glass slide, hand-colored in complimentary colors, for demonstrating retinal fatigue and negative after-images.

Motion Pictures

Clouds. 16- or 35-mm sound films, 11 min. *U. S. Dept. of Agriculture* (Div. of Motion Pictures, Ext. Service, Washington), loaned gratis. Types and formation of clouds, and their significance in weather forecasting.

Diesel Engines. 16-mm sound film. *General Motors Corp.* (1775 Broadway, New York), loaned gratis. Two reels: operating principles of a Diesel engine, 15 min; application of Diesel engines to railroads, 10 min.

Nickel and Copper. 16- or 35-mm sound film. *D. D. Rothacker* (729 Seventh Ave., New York), loaned gratis. Three reels on the mining, smelting and refining of nickel; 1 reel on copper smelting.

How to Use Your Camera. 16-mm silent, 15 min. *Harmon Foundation* (140 Nassau St., New York), rental. The fundamentals for successful amateur motion picture photography.

Erpi Classroom Films. Three films, 16- or 35-mm, sound film, 11 min each. *Erpi Classroom Films* (35–11 35th Avenue., Long Island City, N. Y.), for sale only. (1) *Fuels and Heat* describes the role of carbon in fuels, manufacture and storage of carbohydrates by plants, the process of combustion, and the operation of steam and internal combustion engines. (2) *Distributing Heat Energy* deals with various heat sources, operation of coal, oil and gas furnaces, home heating, and transfer of heat by conduction, etc. (3) *Thermodynamics* treats molecular action in heat transfer, combustion, steam engines and turbines, automobile and Diesel engines, and the first and second laws of thermodynamics.

Appointment Service

Positions Wanted

25. Ph.D. Yale. Age 33, married, 2 children. Industrial research experience; 3 yrs instructor in small college. Interested in teaching in coeducational or men's liberal arts college.

26. Ph.D., with long experience in an American college in China, wishes a college teaching position.

27. Ph.D., physics, Northwestern '35; A.B., engineering, Harvard. Age 42, married, 3 children. Experience: 1 yr, lt., artillery; 12 yrs business and sales; 5 yrs college teaching. Interested in undergraduate teaching, including astronomy.

29. Ph.D., Northwestern; M.S., Pittsburgh; A.B., Muskingum. Age 34, married, 1 child. Has had 13 yrs teaching experience in two universities. Interested in teaching and research.

30. Ph.D., Univ. of Chicago. Many years experience as head of department of physics in prominent college. Author of books on physics and history of science. Large work on history of physics in preparation. Interested in college or university teaching.

31. Ph.D. Columbia. Years of experience as head of departments of physics in colleges and universities. Author of new type of laboratory manual. Designer of many new types of simplified apparatus. Research in radio, acoustics and methods of teaching physics.

33. M.S., experimental physics, coupled with thorough background of courses in professional education. Has taught physics and mathematics for 3 yrs in large high school. Desires position as instructor in high school physics in a university or college experimental or training school.

34. Ph.D., M.S., Penn State. Age 38, married. 13 yrs teaching experience in colleges and universities; 3 yrs head of department in small college; industrial research experience. Interested in teaching, research and administrative work in a small college.

Positions Available

1. Stenographer-secretary for a physics journal. Must be good typist and able to take shorthand. Beginning salary, $70 per month, with privilege of taking one graduate course each semester.

2. Science Editor, Cooperative Test Service, 15 Amsterdam Ave., New York, N. Y. Salary, $1800–2400.

3. Part-time assistant in physics, Hofstra College, Long Island, N. Y. Stipend, at least $700. Duties involve 8–12 clock-hours of elementary laboratory supervision and grading of about 50 laboratory reports weekly.

DIGEST OF PERIODICAL LITERATURE

Apparatus and Demonstrations

An uncommon method for the determination of g. H. Landsberg; *Science* **89**, 245–46, Mar. 17, 1939. A motor is supported with the axle in a vertical position. The speed of the motor is adjusted until a small weight suspended from the axle by a string swings as a conical pendulum of predetermined constant vertical altitude h. A cathetometer or telescope is used to determine h and a revolution counter attached to the axle is used to find n, the number of revolutions per unit time. Then, $g=4\pi^2n^2h$. The method can be refined by controlling h and n by a photoelectric cell, and by placing the apparatus in a vacuum.—D. R.

Two new exhibits. R. S. Clay; *J. Sci. Inst.* **16**, 52, Feb., 1939. To demonstrate beats, D. S. Richards suspends two weights by springs to oscillate with nearly the same period. To them is attached a loop of string supporting a light pulley with a pointer. When the oscillating weights are out of phase, the pointer will rotate; when they are in phase, the pulley rises and falls without rotation.

The device in Fig. 1, shown by Messrs. W. and T. Avery, is a form of the "Roberval enigma" referred to in the

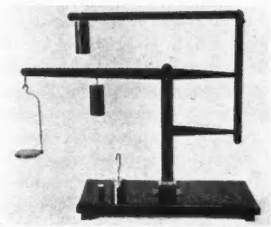

Fig. 1. Extreme form of "Roberval enigma."

Journal des Savants in 1670 where, as in some balances, the position of the load on the pan is immaterial and the weight may be removed to the other side of the fulcrum without disturbing the equilibrium.—H. N. O.

The Separatist Movement in Engineering

Impacts of the E. C. P. D. accrediting on physics. D. S. Elliott; *J. Eng. Ed.* **24**, 325–29, Dec., 1938. This article deals with possible consequences to physics arising out of the recent accrediting of engineering curriculums by the Engineering Council for Professional Development. The writer, for a number of years chairman of the physics committee of the Society for the Promotion of Engineering Education, regards the basic engineering course, amplified by a more extended training in physics, as excellent preparation for the industrial or applied physicist. He has also persistently advocated more latitude in the choice of physics courses as electives in engineering. Furthermore, together with others, he believes that the engineering school should provide training for the physical engineer or engineering physicist. This article voices some anxiety for the future of this educational ideal as a result of the E. C. P. D. accrediting.

In the last analysis the E. C. P. D. accrediting looks to the licensing of engineers; and for that reason the motive is essentially, though unconsciously, economic. Because of the distinction between engineers, in conformity with the four "founder societies," the E. C. P. D. found it necessary to accredit specific engineering courses rather than engineering colleges. It is believed that this accrediting of courses rather than colleges may result in intracompetitions between groups such as electrical engineering and physics, and mechanical and chemical engineering; and that other deleterious effects may result from calling certain departments "major" departments and others, "service" departments. For example, it would be most lamentable if the desire of each department to maintain supervisory control should result, by a sort of senatorial courtesy, in a sacrosanct attitude that the head of each degree-granting department (or at least the heads of these degree-granting departments combined) carry the undivided responsibility for all useful decisions concerning not only his own subject but also the sciences in particular and all other "service" subjects in general. Physics, like other "service" subjects, has already found itself in a defensive position in some places.

This separatist movement in engineering, according to some advices, has resulted in the search for free time for specialist subjects which might be inserted at the expense of physics "service" time. The formation of the differentiated engineering societies, with active student branches recruiting down as far as the freshman year, cannot help but spread confusion and decrease the importance of physics in the minds of students, parents, engineering administrators and the public. The licensing law with its emphasis on graduation from an engineering curriculum might, in the last analysis, deprive the physicist of his economic market as a practicing applied scientist. It may seem doubtful that industry, which absorbs most engineering graduates, will permit the passage of an unfair licensing law; nevertheless, the situation has potentialities full of danger to physics. Perhaps, in the long run, physicists will have to fly their own flag and be alert to their own professional protection.—D. R.

Motion of a Projectile

The motion of a relativistic particle in a uniform field of force. L. A. MacColl; *Am. Math. Mo.* **45**, 669–76, Dec., 1938. The motion of a particle subjected to a constant force is determined by means of relativistic dynamics. When the particle moves in a direction other than that of the force, its trajectory is a catenary rather than the classical parabola. As the time approaches $\pm\infty$, the velocity

component perpendicular to the force approaches zero, while the parallel component approaches the speed of light. This is a consequence of the dependence of the perpendicular component of momentum, which is conserved, on the parallel as well as on the perpendicular velocity component. Expressions are derived for the optimum angle of fire of a projectile, θ_m, for the range R_m and for the maximum ordinate h_m at this optimum angle, as functions of the muzzle speed u. Starting at the classical value of 45°, for small values of u, θ_m increases monotonically to a limiting value of about 56°27′57″.01 as u increases indefinitely; for large values of u, both R_m and h_m are asymptotically proportional to u, instead of to u^2 as in classical theory. For given values of the angle of fire and of the magnitude of the initial momentum, the times of flight for projectiles in the classical and relativistic cases, respectively, are equal.—H. N. O.

Why Teach Metric Units?

Scientific features of the common system of weights and measures. K. G. Irwin; *Sch. Sci. and Math.* **39**, 126–33, Feb., 1939. Physics classes have for many years placed major emphasis upon the use of metric units in problems and laboratory measurements. Yet few students use metric units after leaving school or college. Mechanical, civil and chemical engineers use the common weights and measures; and so do most other professional and trades groups. In explanation the physics instructor claims that the metric system is definitely more scientific and its decimalized units are more easily used.

As to whether the common system is constructed upon a scientifically unsound basis, and whether it is possible to use the common units decimally, are questions for which the author of this article seeks a constructive answer. Some unfamiliar history is introduced in connection with the development of the common system; for example, the explanations as to why coins were once used as weights, why pounds are abbreviated as "lb" and "£," and why our mile is not 5000 ft. General conclusions drawn are that there is nothing to indicate that metric units are going to displace common units in the English-speaking nations, that the common system is being simplified, and that there is a growing tendency toward the decimalization of the inch, ounce and cubic foot to meet technical and precision needs.

The common units of weight have a highly scientific basis. In the Roman time the weight of 1 ft³ of water was the real unit of weight, and was divided into 1000 oz. This relation between the cubic foot and the ounce still exists, though it seems to be seldom realized. The weight of 0.001 ft³ of water at its maximum density is today 0.999 oz. Ordinary tables of density now reading grams per milliliter or kilograms per liter would be correct if expressed as kilo-ounces per cubic foot. This change would simplify the handling of specific gravity also. It can be further noted that the use of the gram-molecular-volume as 22.4 l may have as its substitute the use of the ounce-molecular-volume of 22.4 ft³.

In early England a pint of wine was a pound of wine, and the fluid ounce was the capacity of an ounce of wine. The British Empire has made this system more modern by making the pint a pound of water, and the fluid ounce the capacity of an ounce of water. This pint is used both for liquid and dry measure. The fluid ounce is divided decimally, and, of course, the fluid ounce itself is a decimal division of the cubic foot.

There would seem to be few real difficulties in the way of a wider use of the common units in physics classes. For laboratory use we need inches divided decimally (as the barometer already has them), weighing devices permitting the decimal handling of ounces (a plan already in use to some extent), and graduates and burettes divided into decimal parts of the cubic foot (as is already prevalent in England).—D. R.

Science Teaching in 1950

The program for science in 1950. M. Meister; *Sch. Sci. and Math.* **39**, 103–16, Feb., 1939. The author, who is director of the recently established High School of Science in New York City, prophesies that the purposes of science teaching on the secondary school level will be for general, rather than vocational, education. Its products will be the *good citizen* and the *intelligent consumer* rather than the *efficient breadwinner* and the *skilful producer*. College preparation for the few will give way to preparation for adult living for all, with particular emphasis upon the development of scientific thinking and scientific attitudes, so essential for active citizenship in a free democracy. The establishment of a twelve-year science sequence will call for considerable modification of the present grade-placement of subject matter. On the secondary school level, subject matter will be reorganized around student needs and varying ability. Courses and, in large school systems, even schools will have to be correspondingly multiplied. More attention than heretofore will be given to inter-subject correlation, with "core" subjects assuming the integrating role. Science lends itself admirably as such a "core" subject. The science student will be subjected to richer and even more effective experiences as competent educators master the technics of visual and auditory aids, of which the potentialities for artistic teaching have as yet barely been touched. Teaching will become more leisurely and less of a race to "cover ground." In the laboratory of 1950, the student will pursue truth as problems arise, in the manner of the scientist. The science club will become coordinate in its value with the science class. The science teacher will come from a professional school and not an academic college.—D. R.

Check List of Periodical Literature

Particles of the cosmic rays. K. Darrow; *Sci. Mo.* **48**, 326–44, Apr. 1939. A survey.

The ionosphere. E. O. Hulburt; *Sci. Mo.* **48**, 421–30, May 1939. A survey.

History in the archives of the Royal Society. W. Bragg; *Science* **89**, 445–53, May 19, 1939. Includes some excellent suggestions on the popularization of scientific knowledge.

The construction of a water hammer—a student project in glass blowing. R. A. Baker; *J. Chem. Ed.* **16**, 247–48, May 1939. Detailed instructions for making a demonstration water hammer from broken flasks.